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'Best Management Practices' for Salinity Control in Grand Valley

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"Best Management Practices" for Salinity Control in Grand Valley

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A nontechnical summary of several research activities in the Grand Valley is given. Analyses of alternative measures of reducing the salt load originating from the Valley as a result of irrigation return flows are presented. These alternatives include conveyance channel linings, field relief drainage, on-farm improvements (such as irrigation scheduling, head ditch linings, sprinkler and trickle irrigation), economic control measures such as taxation and land retirement, modified legal constraints, and collection and treatment of return flows with desalting systems. The best management practices for salinity control in the Grand Valley should be primarily the structural rehabilitation and operational modification of the local irrigation system lying below the turnouts from the major canal systems. Canal linings appear in the optimal strategies at higher levels of valley-wide salinity control emphasis but only so far as lining the Government Highline Canal is concerned. Desalting would become a cost-effective alternative after major irrigation system improvements are implemented.

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"BEST MANAGEMENT PRACTICES" FOR SALINITY CONTROL IN GRAND VALLEY

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

William C. Galegar

William C. Galegar
Director
Robert S. Kerr Environmental
Research Laboratory

PREFACE

The Department of Agricultural and Chemical Engineering at Colorado State University has conducted several research programs which deal directly or indirectly with the Grand Valley Salinity Control problem. This report is the last in a series of three describing the results obtained in one of these programs, Grant No. S-802985, "Implementation of Salinity Control Strategy in Grand Valley." However, it is intended to be a somewhat nontechnical summary relating to the Grand Valley, and includes results of supportive studies reported by the writers.

The major technical series of reports from which this report is generated is listed below, a full description is cited in the references:

Grant No.	Report Title	Date
14-01-201	Evaluation of Canal Lining for Salinity Control in Grand Valley	Oct. 1972
S-800278	Evaluation of Irrigation Scheduling for Salinity Control in Grand Valley	June 1974
S-800278	Evaluation of Drainage for Salinity Control in Grand Valley	Aug. 1974
S-802985	Implementation of Salinity Control Technology in Grand Valley	In Press
S-802985	Evaluation of Irrigation Methods for Salinity Control in Grand Valley	In Press
S-800687	Irrigation Practices and Return Flow Salinity in Grand Valley	In Review
S-800687	Potential Effects of Irrigation Practices on Crop Yields in Grand Valley	In Review

In addition to these major technical reports, there are several supportive studies which apply to the Grand Valley in at least some aspect. These are:

Grant No.	Report Title	Date
R804303	Achieving Irrigation Return Flow Quality Control through Improved Legal Systems	In Press
R803572	Socio-Economic and Institutional Factors in Irrigation Return Flows Quality Control	In Review
R803869	Integrating Desalination and Agricultural Salinity Control Alternatives	In Press
R804828	Assessing the Spatial Variability of Irrigation Water Applications	In Press

Many of the above reports have been utilized in the writing of these reports in order to present a broad consideration of "Best Management Practices" in the Grand Valley. Nearly all of the analytical procedures are left to the reader to evaluate in the technical reports.

ABSTRACT

A nontechnical summary of several research activities in the Grand Valley is given. Analyses of alternative measures of reducing the salt load originating from the Valley as a result of irrigation return flows are presented. These alternatives include conveyance channel linings, field relief drainage, on-farm improvements (such as irrigation scheduling, head ditch linings, sprinkler and trickle irrigation), economic control measures such as taxation and land retirement, modified legal constraints, and collection and treatment of return flows with desalting systems.

The best management practices for salinity control in the Grand Valley should be primarily the structural rehabilitation and operational modification of the local irrigation system lying below the turnouts from the major canal systems. Canal linings appear in the optimal strategies at higher levels of valley-wide salinity control emphasis but only so far as lining the Government Highline Canal is concerned. Desalting would become a cost-effective alternative after major irrigation system improvements are implemented.

Field drainage, taxation, and land retirement are not considered reliable control alternatives because of cost and marginal effectiveness. The legal measures are unlikely candidates in a salinity control program directly, but will play an important role in implementing the practices which reduce salt loading directly.

This report was submitted in fulfillment of Grant No. S-802985 to Colorado State University, under sponsorship of the Environmental Protection Agency. This report covers the period February 18, 1974 to June 17, 1977, and was completed as of January 31, 1978.

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Four people have been instrumental in the pursuit of this research program almost from its inception. The Project Officer, Dr. James P. Law, Jr., has been an active participant in the planning and development of the research approach, and his long-term efforts and cooperative attitude that have allowed this research program to be brought to a logical conclusion are greatly appreciated. My colleague for many years, Dr. Wynn R. Walker, has contributed most significantly to this research effort in taking responsibility for much of the analysis. Mr. George Bargsten, who began this research program with me in September 1968 and continued throughout to be largely responsible for the field data collection, has my respect and gratitude for his many years of hard, diligent work. Much of the experimental design each year was dictated by the capability of our water quality laboratory in Grand Junction, and this responsibility fell upon Ms. Barbara F. Mancuso, who was meticulous in the laboratory procedures, diligent in getting the samples analyzed, and remained cheerful under pressure.

There are many people and organizations in the Grand Valley who should be thanked for their contributions to this research effort. Mr. Bob Henderson and Mr. Bill Klapwyck, who are Managers of the Grand Valley Irrigation Company and Grand Valley Water Users Association, respectively, have been deeply involved in this research since its inception and have always been very helpful in providing ideas and getting the work done. Mr. Chuck Tilton, Superintendent of the Grand Junction Drainage District, has also been heavily involved in the construction activities and very helpful to the farmers participating in this research program. The soil chemistry and crop yield studies were done on land leased from Mr. Kenneth Matchett, an outstanding citizen and farmer who was cooperative and more than helpful.

During the course of this project, three engineers served in Grand Valley and were responsible for field operations; namely, Mr. Orlando W. Howe, Mr. Ray S. Bennett, and Mr. Robert G. Evans. I would particularly like to acknowledge the efforts of Mr. Evans, who took responsibility for all of the construction activities involved with the lateral improvements during the final demonstration phase.

The project benefited considerably from the many students who participated in the research activities, particularly those

who spent 4-5 years with the project; namely, Mr. James H. Taylor, Mr. Ted L. Hall, Dr. James E. Ayars, Mr. Berry J. Treat and Mr. Charles W. Binder. Although he spent a shorter time period on the project, Dr. J.W. Hugh Barrett contributed significantly in his research on crop yield functions.

Finally, the individuals who should be acknowledged the most are the farmers who participated in this research program. We learned much from them. From irrigating some fields for a few seasons ourselves, to studying irrigation problems and farmer constraints, to modifying irrigation practices, to constructing physical improvements and the enormous task of operating these new systems as effectively as possible, it was all a tremendous learning and sensitizing experience.

My sincerest thanks to all of you.

Gaylord V. Skogerboe
Principal Investigator

SECTION 1

INTRODUCTION

COLORADO RIVER SALINITY PROBLEM

Mineral pollution is the most serious water quality problem in the Colorado River Basin (Figure 1). The problem is serious because the Basin is approaching conditions of full development and utilization of the available water resources. Thus, while the salinity problem may seem unique to basins of the arid West, it will ultimately be faced by nonarid areas as the water use approaches the available supply. Thus, the salinity control program developed for the Colorado River Basin may be expected to serve as a model for future programs in other basins.

The most serious problems resulting from the saline flows are experienced in the Lower Colorado River Basin. Increasing salinity concentrations are threatening the utility of water resources in the downstream areas of Arizona, California, and the Republic of Mexico. Detriments to agricultural water users are primarily being encountered in Imperial and Mexicali Valleys, while the primary urban detriments are occurring in Los Angeles and San Diego. The U.S. Environmental Protection Agency (1971) reported that existing damages to Lower Basin users would increase from $16 million annually in 1970 to $51 million annually by the turn of the century if planned developments do not include appropriate salinity control measures, while more recent estimates by the U.S. Bureau of Reclamation (USBR) (Bessler and Maletic, 1975) show present damages at $53 million annually, which is projected to be $124 million annually by the year 2000.

Approximately 10 million metric tons (11 million tons) of salts are delivered each year in the water supply serving the Lower Colorado River Basin. These salts reach Hoover Dam in about 1.36 million hectare-meters (11 million acre-feet) of water. Studies have indicated that roughly 37 percent of this salt load is contributed by irrigated agriculture in the Upper Colorado River Basin (Figure 2). Present salinity concentrations necessitate treatment of water for both municipal and industrial uses throughout the Lower Basin. In fact, concentrations at times approach the tolerance of many high value crops such as citrus, thus requiring the use of excessive quantities of water for leaching and expensive water management programs.

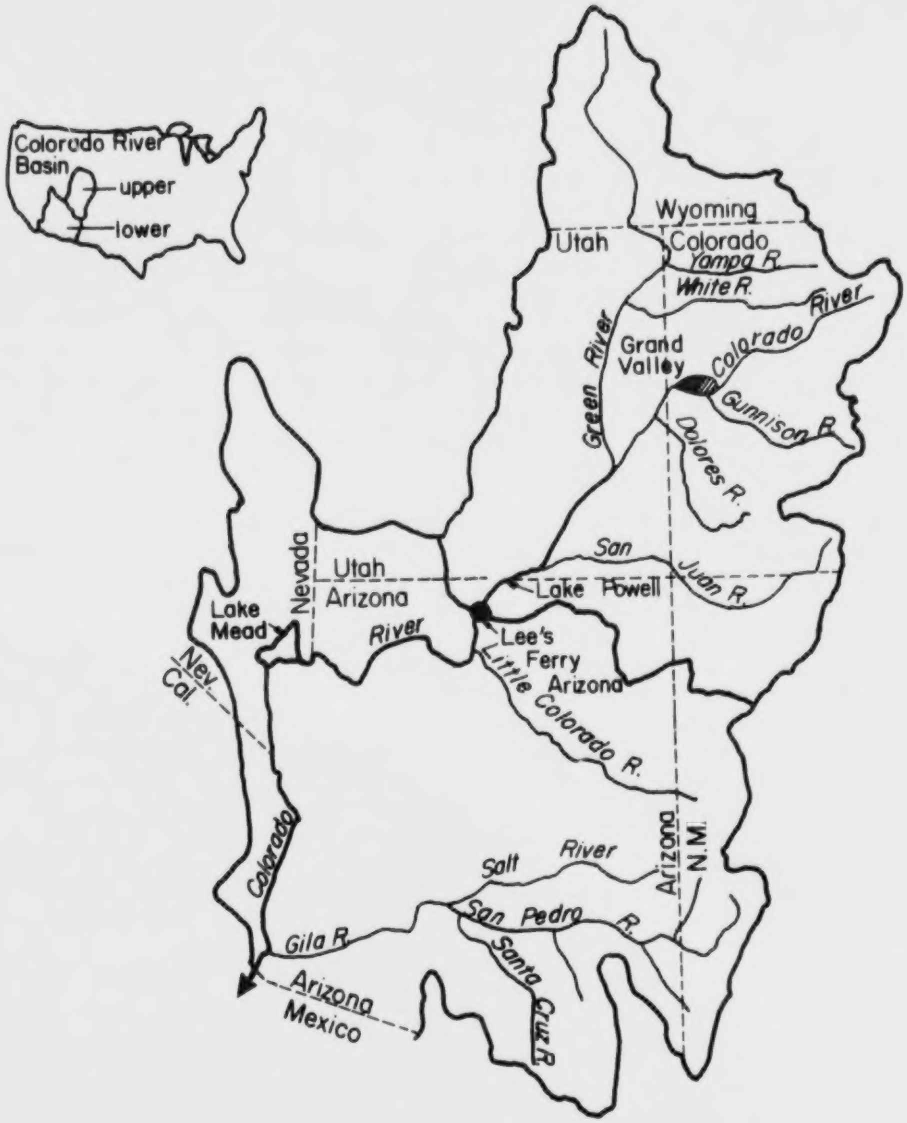

Colorado River Basin
upper
lower
Wyoming
Utah
Colorado
Yampa R.
White R.
River
Green River
Grand Valley
Colorado
Gunnison R.
Dolores R.
San Juan R.
Nevada
Utah
Arizona
Lake Powell
Lake Mead
River
Lee's Ferry
Arizona
Nev.
Cal.
Little Colorado R.
Colorado
Salt River
Arizona
N.M.
San Pedro R.
Gila R.
Santa Cruz R.
Arizona
Mexico

Figure 1. The Colorado River Basin.

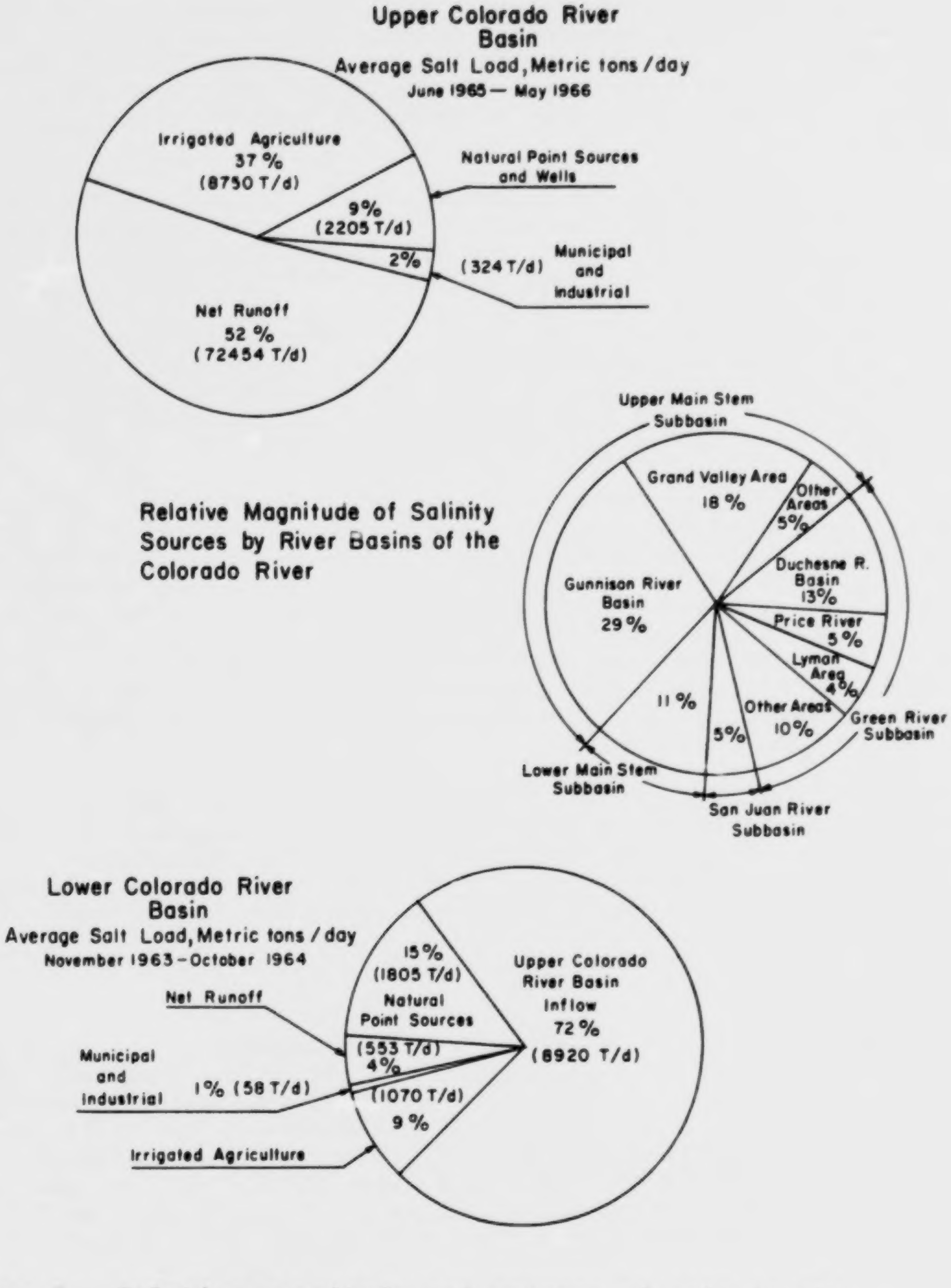


Figure 2. Relative magnitude and sources of salt in the Colorado River Basin (U.S. Environmental Protection Agency, 1971).

The water quality problem in the Colorado River Basin has obviously become chronic before full utilization of the water resources has been realized. The philosophy surrounding future developments will probably be one of accompanying each development with a corresponding decrease in the salt load somewhere else in the Basin in order to maintain present water quality levels.

The Upper Basin water users are particularly affected by these conditions because most of the future developments involve interbasin transfers, in-basin oil shale developments, and possible hydroelectric and thermalelectric production. None of these water uses add significantly to the salt loading aspect, but each diminish the quantity of water available for diluting the salt loads already being carried. Consequently, future development of water resources in the Upper Colorado River Basin must be associated with more rigid salinity controls on the existing salt sources, many of which are agriculture related.

In irrigated areas, it is necessary to maintain an acceptable salt balance in the crop root zone, which requires some water for leaching. However, when irrigation efficiency is low and conveyance seepage losses are high, the additional deep percolation losses are subject to the highly saline aquifers and soils common in the basin and result in large quantities of salt being picked up and carried back to the river system. Therefore, a need exists to delineate the high input areas and examine the management alternatives available to establish the most effective salinity control program.

That portion of the water supply which has been diverted for irrigation but lost by evapotranspiration (consumed) is essentially salt-free. Thus, the water percolating through the soil profile contains the majority of salts originally in the water supply and left behind by the water lost to evaporation and transpiration. The net result is that the percolating soil water contains a higher concentration of salts. This is referred to as the "concentrating" effect.

As the water moves through the soil profile, it may pick up additional salts by dissolution. In addition, some salts may be precipitated in the soil and there may be an exchange between some salt ions in the water and in the soil. The salts picked up by the water applied to the land are termed salt "pickup." The total salt load from an irrigated area is the net increase of salt in the irrigation return flows as a result of the concentrating effect plus the salt pickup (minus any precipitation of salts).

The most significant salt source in the Upper Basin is the Grand Valley area (Figure 2) in west central Colorado. The contribution to the total salt flows in the basin from this area is highly significant. The primary source of salinity is from the extremely saline aquifers overlying the marine deposited Mancos shale formation. The shale is characterized by lenses of salt in the formation which are dissolved by water from excessive irrigation and conveyance seepage losses when it comes in contact with the Mancos Shale formation. The introduction of water through these surface sources percolates into the shallow groundwater reservoir where the hydraulic gradients displace some water into the river. This displaced water has usually had sufficient time to reach chemical equilibrium with the salt concentrations of the soils and shale. These factors also make the Grand Valley an important study area, since the conditions encountered in the Valley are common to many locations in the Upper Basin.

THE GRAND VALLEY

General Description

The Grand Valley is located in west central Colorado near the western edge of Mesa County. Grand Junction, the largest city in Colorado west of the Continental Divide, is the population center of the Valley (Figure 3). The Grand Valley is a crescent shaped area which encompasses about 49,800 hectares (123,000 acres) of which 57.7 percent or about 28,650 hectares (70,800 acres) are irrigated. Urban and industrial expansion, service roads and farmsteads, idle and abandoned lands account for most of the land not farmed. The Valley was carved in the Mancos Shale formation (a high salt bearing marine shale) by the Colorado River and its tributaries. The Colorado River enters the Grand Valley from the east, is joined by the Gunnison River at Grand Junction and then exits to the west.

Spectacular and colorful canyons flank the southwestern edge of the Valley (Colorado National Monument). A steep escarpment known as the Book Cliffs (which are the southern edge of the Roan Plateau) rises from the Valley floor on the north; the 3,050 meter (10,000 feet above mean sea level) high Grand level lies to the northeast; and distantly to the southeast the San Juan Mountains can be seen; to the south and west lie the rough, steep, deeply eroded hilly lands of the high terraces or mesas of the canyon lands of the Colorado Plateau. Within the Grand Valley, the irrigated lands have been developed on geologically recent alluvial plains consisting of broad coalescing alluvial fans and on older alluvial fans, terraces and mesas. Included in the Valley lands are stream flood plains and various rough lands occurring as terraces, escarpments, high knobs, and remnants of former mesas.

The majority of the population of Mesa County resides in the Grand Valley near and within the city limits of Grand Junction.

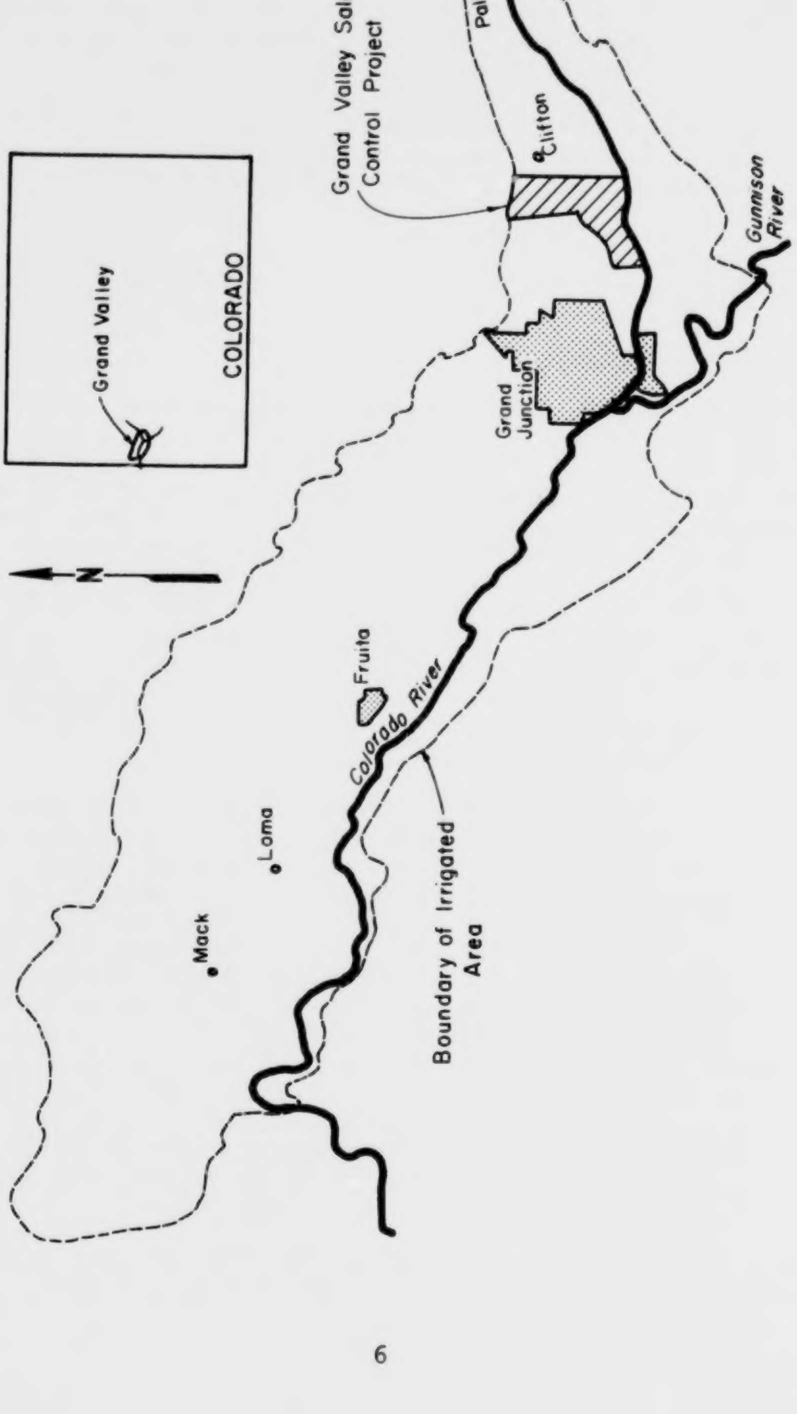

Grand Valley
COLORADO
N
Grand Valley Salinity Control Project
Palisade
Clifton
Gunnison River
Grand Junction
Fruita
Colorado River
Loma
Mack
Boundary of Irrigated Area

Figure 3. The Grand Valley, Colorado.

In 1970 the population of the city of Grand Junction was 20,170, which was 37 percent of the total Mesa County population. The population has been growing steadily during the past decades, and the 1974 estimated population of Grand Junction was 27,000 while that of Mesa County was nearly 62,000. The projected 1990 population of Mesa County is 90,000.

Grand Junction is a regional trade and service center for the considerable agricultural and mining interests in western Colorado, northwestern New Mexico, northeast Arizona, and eastern Utah because of its access to major highways, rail and airline systems. During the 1950's the area became and has remained the center of the uranium exploration boom and several uranium development projects sponsored by the government. Recent program expansions related to energy have caused an economic upswing for the area. At the present time, the Grand Valley is a focal supply point for the budding oil shale and sodium bicarbonate (Nahcolite) industries which lie to the north and west. The area is also a supply and service center for a considerable oil and natural gas drilling and exploration industry.

The diversified agricultural industry in the Valley is comprised of both livestock and crop production activities. Slightly less than 10 percent of the irrigated acreage is planted to pome and deciduous orchards, the produce of which is processed locally and may be shipped as far as the Atlantic seaboard. The Grand Valley has long been a favored wintering area for cattle and sheep which were grazed on high mountain summer ranges to the east and north (Young et al., 1975).

An economic survey by Leathers (1975), along with the land use inventory by Walker and Skogerboe (1971), indicates that local farming is primarily a small unit operation. The population engaged in agricultural activities is widely dispersed throughout the Valley with most living on their property. Leathers (1975) determined from sampling about 100 random selections that most farm units were less than 40 hectares (100 acres) in size. Of the total of 7,870 fields in the Valley, 50 percent are less than 2 hectares (5 acres) in size (United States Department of Agriculture-Soil Conservation Service (USDA-SCS), 1976).

The Grand Valley receives an average annual precipitation of only 211 mm (8.29 inches) and practically all irrigation and potable water supplies come from the nearby high mountain snowpacks. The climate is marked by a wide seasonal range, but sudden or severe weather changes are infrequent due primarily to the high mountains surrounding the Valley. The usual occurrence of precipitation in the winter is snow and during the growing season is in the form of light showers from thunderstorms. Severe cloudbursts occur infrequently during the late summer months and hail storms are rare. Although temperatures have ranged to as high as 40.6 degrees C (105 degrees F), the usual summer temperatures range to the middle and low 30's degrees C (90's degrees F) in the daytime and around 15 degrees C (low 60's degrees F) at night. Relative humidity is usually low during the growing season, which is common in all of the semi-arid Colorado River Basin. The average annual relative humidity is 58.8 percent. The prevailing wind direction is east-southeast with an average velocity of about 13.4 kilometers per hour (8.3 mph).

Enough variation in climate exists in the Valley to separate the agricultural land use into three primary regions. In the eastern end of the Valley, the protective proximity to the abrupt Crand Mesa results in extended periods of frost-free days which allows apple, peach, and pear orchards to abound. In the western half of the Valley, the primary emphasis is on producing corn, alfalfa, sugar beets, and small grains. (Sugar beets are presently not grown in the Valley due to the closure of the Holly Sugar factory in the fall of 1976.) Between these two regions is a transition zone of small farms and the urban setting of Grand Junction, the population center of the area.

Historical irrigation development in the Grand Valley was reported in detail in an earlier EPA report, "Evaluation of Canal Lining for Salinity Control in Grand Valley," (Skogerboe and Walker, 1972) and only a very brief summary will be presented here.

Although the early explorers concluded that the Grand Valley was a poor risk for agriculturally related activities, the first pioneering farmers rapidly disproved this notion with the aid of irrigation water diverted from the Grand and Blue Rivers (now the Colorado and Gunnison Rivers, respectively) entering the Valley. Through a long struggle, an irrigation system evolved to supplement the otherwise meager supply of precipitation during the hot summer months. The first large-scale irrigation in the Valley began in 1882 with the construction of the Grand Valley Canal (now the Grand Valley Irrigation Company), which was privately financed. Other private systems were built during the period between 1882 and 1908 when construction started on the last major system, which was the Grand Valley Project by the USBR. The last major construction was completed in 1926: The Grand Valley Project consists of two divisions: The Garfield Gravity Division and the Orchard Mesa Division on the north and south sides of the river, respectively.

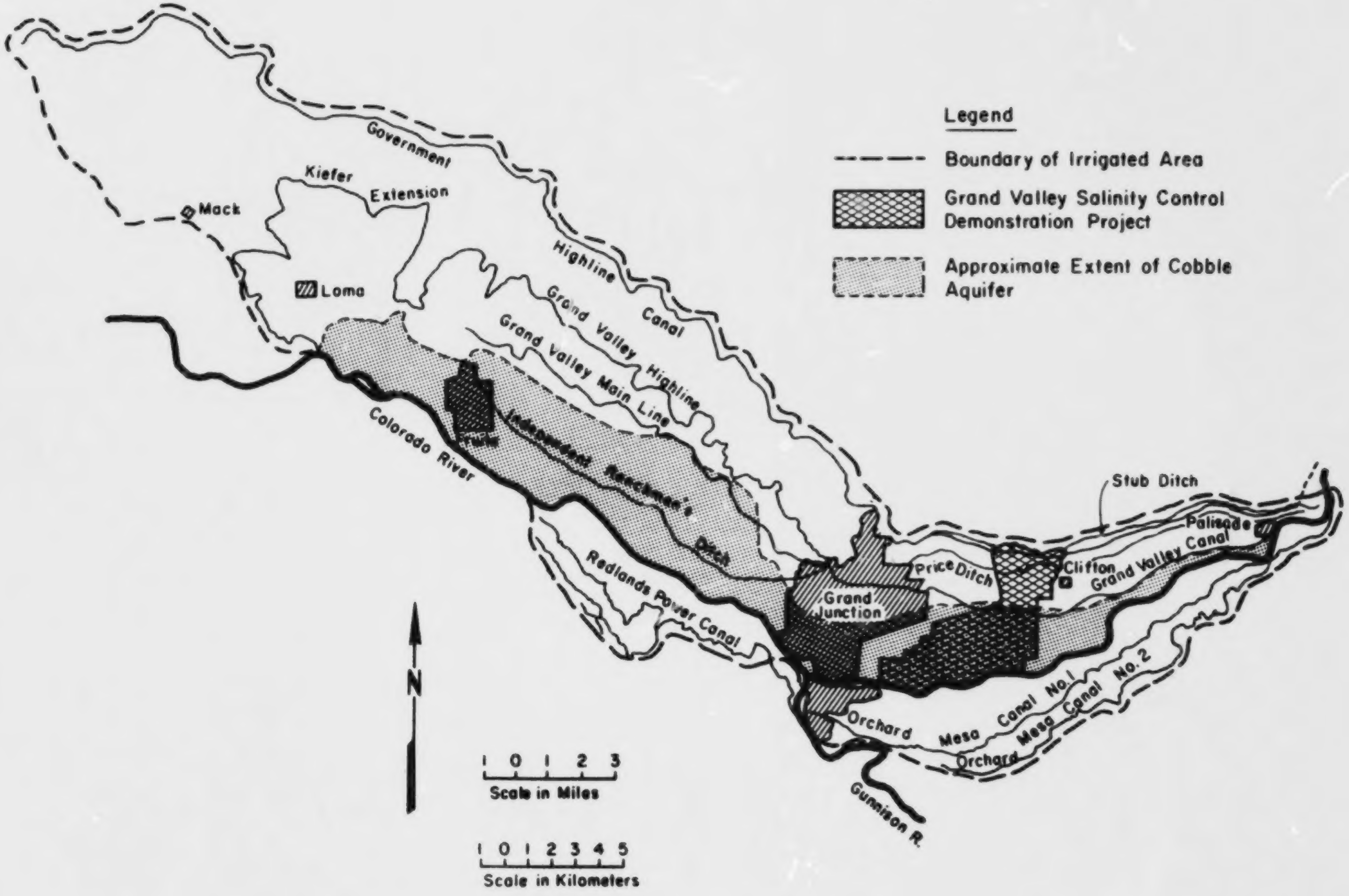
The futility of irrigation without adequate drainage was quickly demonstrated to early settlers in the Valley as some low lying acreages became waterlogged with highly saline groundwater. Today, the failure to completely overcome these conditions is still evident. For example, of the more than 28,600 hectares (70,800 acres) of irrigable cropland, almost one-third is either in pasture or idle. An examination of land use in Grand Valley by Walker and Skogerboe (1971) indicated a large fraction of the 12,000 to 16,000 hectares (30,000 to 40,000 acres) of phreatophytes and barren soil were once also part of the irrigated acreage. Evidence exists that these same lands were once highly productive and subsequently ruined by overirrigation and inadequate drainage.

Two main irrigation entities divert water from the Colorado River. These are the Grand Valley Water Users Association (USBR Project) and the Grand Valley Irrigation Company. A third irrigation company, the Redlands Power and Water Company, diverts water from the Gunnison River. A number of smaller companies have carriage agreements with the two major canals for delivery of Colorado River water. These include the Palisade Irrigation District (Price Ditch) and the Mesa County Irrigation District (Stub Ditch), who have such an agreement with the Grand Valley Water Users Association (Government Highline Canal). The Grand Valley Irrigation Company is composed of several smaller canals, including the Mesa County Ditch, Kiefer Extension, the Independent Ranchman's, and others. The irrigation system of the Valley, consisting of about 287 kilometers of canals, is shown in Figure 4.

Discharge capacities at the head of the canals range from 20 m^3/sec (700 cfs) in the Government Highline Canal to 0.8 m^3/sec (30 cfs) in the Stub Ditch and diminish along the length of each canal or ditch. The lengths of the respective canal systems are approximately 74 kilometers (46 miles) for the Government Highline Canal, 35 kilometers (22 miles) for the Price, Stub, and Redlands Ditches, 125 kilometers (78 miles) for the Grand Valley system, and 53 kilometers (33 miles) for the Orchard Mesa Canals. The capacities, dimensions, and seepage losses of the canals in the Valley are summarized in Tables 4 and 6 in Section 4.

The term lateral is used in this text to refer to those small conveyance channels which deliver water from the company canals to the farmer's fields. These small channels usually carry flows less than 0.14 m^3/sec (5 cfs) and range in size up to 1.2 or 1.5 meters (4 or 5 feet) of wetted perimeter. There are about 600 kilometers (373 miles) of laterals in the Grand Valley as determined by the USBR (1976). Not counting the Redlands area of the Valley, there are 1,553 laterals in the Valley (USBR, 1976).

When water is turned into the lateral system, it becomes the responsibility of the users entitled to the diversion and not the ditch company. The only exception is the Government Highline Canal which sometimes treats their larger laterals as small canals and turnout water at headgates on these laterals. However, no effort is made beyond the headgate.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Boundary of Irrigated Area
Grand Valley Salinity Control Demonstration Project
Approximate Extent of Cobble Aquifer
Government
Kiefer
Extension
Mack
Loma
Highline
Canal
Grand Valley Highline
Grand Valley Main Line
Independent Ranchman's Ditch
Fruita
Colorado River
Redlands Power Canal
Grand Junction
Price Ditch
Stub Ditch
Clifton
Palisade
Grand Valley Canal
Orchard Mesa Canal No. 1
Orchard Mesa Canal No. 2
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Scale in Miles
1 0 1 2 3 4 5
Scale in Kilometers

Figure 4. Grand Valley canal distribution system and approximate areal extent of cobble aquifer.

Single users served by an individual turnout are not uncommon, but most laterals serve several irrigators who decide among themselves how the lateral will be operated. Most of the multiple-user laterals, which may serve as many as 100 users, run continuously throughout the irrigation season with the unused water being diverted into the drainage channels. USBR (1976) figures show that the average irrigated acreage served by a lateral is between 10 and 15 hectares (25 to 37 acres).

The prevalent method of applying water to croplands in the Valley is furrow irrigation. Small laterals carrying 0.03 to 0.14 cubic meters per second (1 to 5 cubic feet per second) divert water from the company or district operated canal systems to one or more irrigators. Water then flows into field head ditches where it is applied to the lands to supply moisture to the growing crops and maintain a low salinity root zone environment in order to sustain plant growth.

The predominantly alfalfa, corn, sugar beet, orchard, and small grain economy is served by a more than adequate water supply. The 28,665 hectares (70,830 acres) of irrigable cropland encompassed within the irrigation system enjoys a total diversion of more than 2.4 hectare-meters per hectare (8 acre-feet per acre) during normal years. Considering that the potential evapotranspiration of these croplands is usually less than 0.9 hectare-meters per hectare (3 acre-feet per acre), it is obvious that existing water use efficiencies are low. There is no groundwater used for irrigation purposes. The abandonment and withdrawal of farmlands for other uses has also contributed to the surplus of water since there has been no reduction in diversions. Most of this "excess" water is wasted into the drains.

Geology

The geologic formations throughout the Colorado River Basin were laid by an inland sea which covered the area. After the retreat of the sea, the land masses were uplifted and subsequent erosion has created the mountains and plateaus as they are today. As shown in Figure 5, the upper formations are sandstones and marine shales which are underlaid by the marine Mancos Shale and the Mesa Verde formations. Mancos Shale is a very thick formation that lies between the underlying Dakota sandstones and the overlying Mesa Verde formation. The thickness of the Mancos Shale usually varies from between 900 to 1,500 meters (3,000 and 5,000 feet). Due to its great thickness and its ability to be easily eroded, this shale forms most of the large valleys of western Colorado and eastern Utah. These formations occur in about 23 percent of the Basin in such locations as the Book Cliffs, Wasatch, Aquarius and Kaiparowits Plateaus, the cliffs around Black Mesa and areas in the San Juan and Rocky Mountains. The Grand Valley was created by erosion, which cut through the

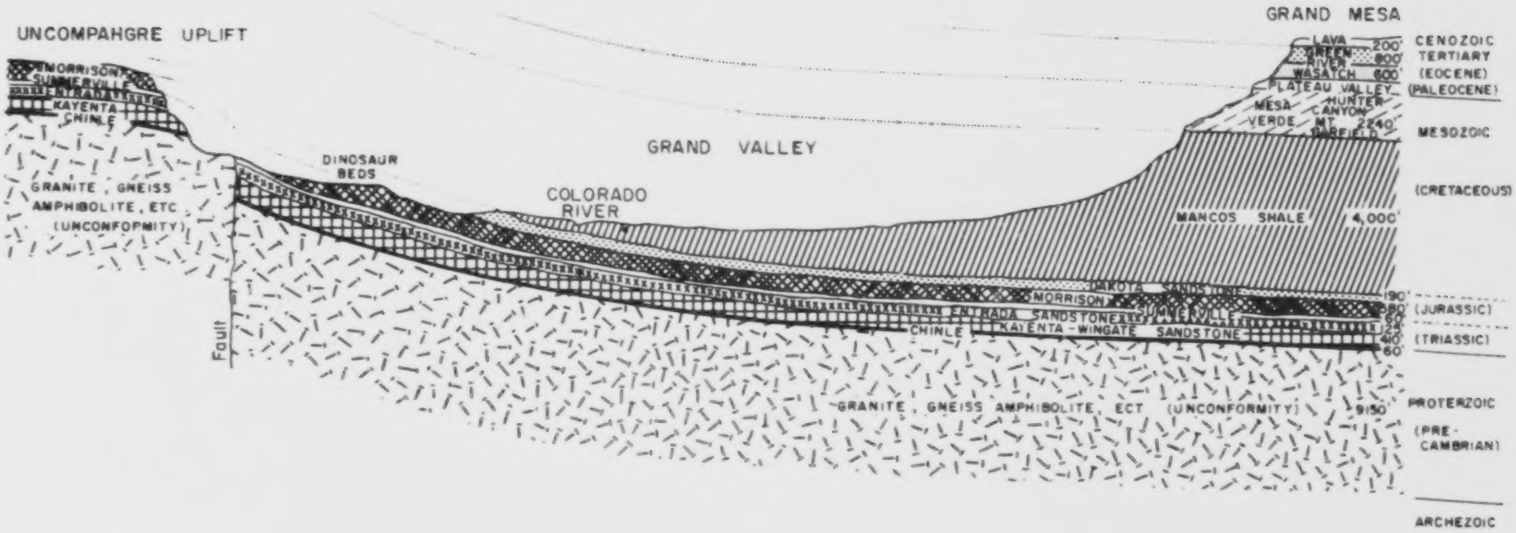

UNCOMPAHGRE UPLIFT
MORRISON
SUMMERVILLE
ENTRADA
KAYENTA
CHINLE
GRANITE, GNEISS
AMPHIBOLITE, ETC
(UNCONFOPMITY)
Fault
DINOSAUR BEDS
GRAND VALLEY
COLORADO RIVER
GRAND MESA
LAVA 200'
GREEN RIVER 800'
WASATCH 600'
PLATEAU VALLEY
MESA VERDE
HUNTER CANYON
MT. GARFIELD
2240'
MANCOS SHALE 4,000'
DAKOTA SANDSTONE
MORRISON
ENTRADA SANDSTONE
SUMMERVILLE
CHINLE
KAYENTA - WINGATE SANDSTONE
190'
580'
60'
25'
40'
60'
GRANITE, GNEISS AMPHIBOLITE, ECT (UNCONFORMITY) 9150'
CENOZOIC
TERTIARY
(EOCENE)
(PALEOCENE)
MESOZOIC
(CRETACEOUS)
(JURASSIC)
(TRIASSIC)
PROTERZOIC
(PRE-CAMBRIAN)
ARCHEZOIC

Figure 5. Geologic cross-section of the Grand Valley.

upper formations creating the Valley in the Mancos Shale. This formation is the main source of the salt contribution to the Colorado River. Due to its marine origin, the shale contains lenses of salt which are easily dissolved as water moves over the shale beds. Water moving over and through the shale originates from overirrigation and leakage from the canals and laterals. Since the overlying soil is derived from the shale, it is also high in salts and contributes significantly to the salinity of return flows.

Because of the marine origin of the shale, it contains a very high percentage of water soluble salts which can be readily seen in the many patches of alkali (white and black) in both irrigated and nonirrigated areas. The types of salts which are present in the shale are mostly calcium sulfate with smaller amounts of sodium chloride, sodium sulfate, magnesium sulfate, and calcium and magnesium carbonates. In fact, the minerals gypsum and calcite (calcium sulfates) are commonly found in crystaline form in open joints and fractures of the Mancos Shale, as well as in the soil profile.

The Mancos Shale is a "dark-gray (black when wet) clayey and silty or sandy, calcareous gypsiferous" deposit of marine origin and Upper Cretaceous in age (Schneider, 1975). In the portion of the Valley lying north of the Government Highline Canal (Figure 4), Mancos Shale is an exposed erosional surface. Essentially no irrigation is practiced in this portion of the Valley. Intermittent ridges of Mancos Shale are exposed in the area bounded, approximately, by the Government Highline Canal on the north and the Grand Valley Canal on the south. These shale ridges have a general north-south trend and represent remnants of a shale terrace which has been dissected by southward flowing streams that began in the Book Cliffs. The southern extremities of these ridges (approximately the Grand Valley Canal) are the remnants of the shale cliffs that once formed the northern bank of the Colorado River (Schneider, 1975).

With time, the Colorado River migrated southward in an approximately horizontal plane until it reached its present position. During this period, the river deposited what is now a cobble aquifer that extends from the present river location northward to, approximately, the Grand Valley Canal (Figure 4). Migration of the Colorado River to the south decreased the gradient of southward flowing tributaries, and the Valley was gradually filled with alluvial deposits transported by the tributaries. These tributary deposits buried the Colorado River bedload and flood plain deposits (Schneider, 1975). It is the tributary alluvium, deposited during the Quaternary, that forms the source of most of the irrigated soils in the Valley. In recent time, local washes have again cut down into the alluvial deposits and into the Mancos Shale at many locations.

Recent downcutting into the Mancos Shale bedrock is most prevalent near the north edge of the irrigated region where the tributary deposits are relatively thin.

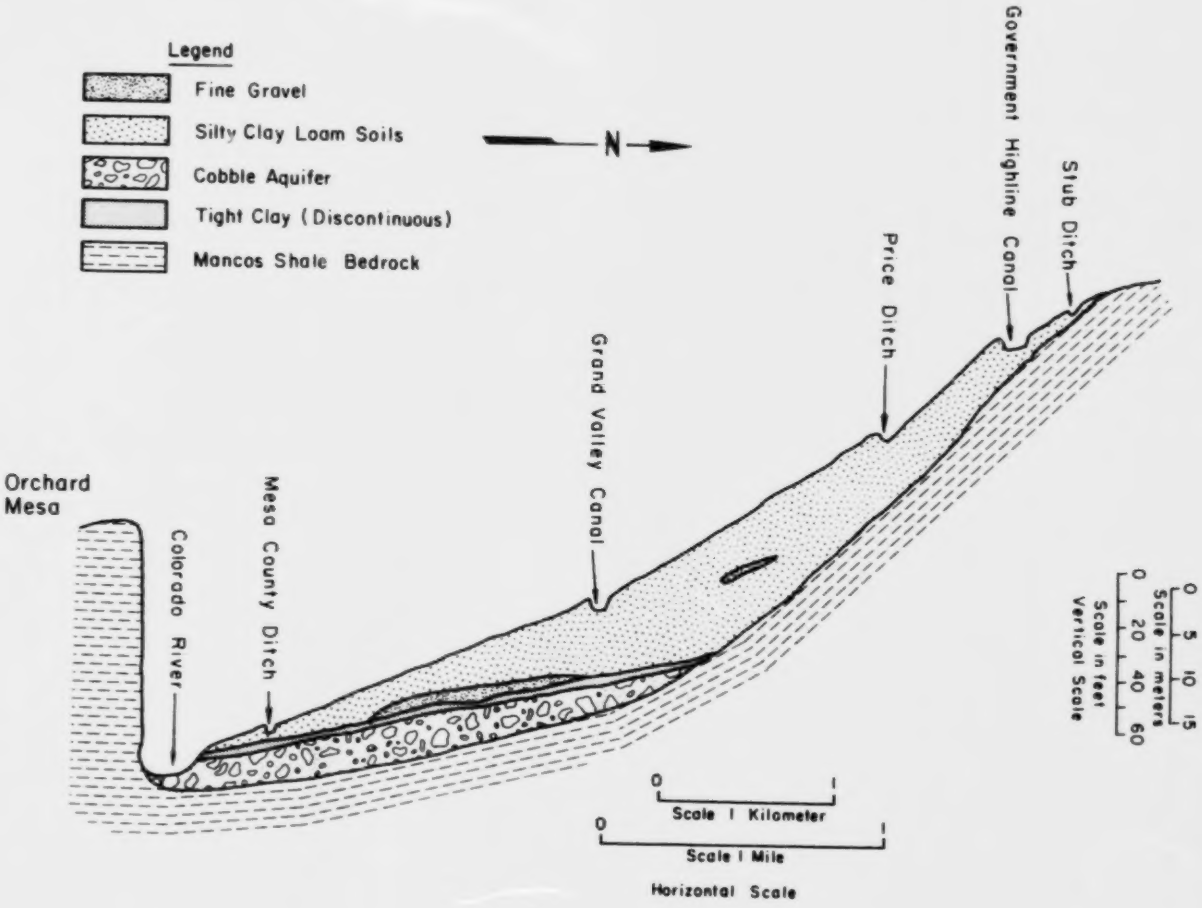
The alluvial deposits overlying the cobble aquifer and/or the Mancos Shale are saline clays and silts derived mainly from Mancos Shale in the Book Cliffs area and from shaly members of the Mesa Verde Group. Where the cobble aquifer is absent, the clay soils are in contact with a weathered shale zone, below which is the unweathered Mancos Shale. Due to the compactness of the clay and silt particles making up the shale, the formation is not considered water-bearing at depth. However, the weathered zone near the surface does transmit small quantities of water along joints, fractures, and open bedding planes. In this zone, the percolating water, which primarily originates from the overirrigation of cropland and seepage losses from canals and laterals, dissolves the salts directly out of the shale. The weathered shale can be recognized by its brownish-gray to brown color as compared to the darker gray of the unweathered shale. The weathered shale also exhibits joints, and disintegration and separation along the bedding planes. These features account for the permeability of the weathered shale.

The cobble aquifer that underlies the tributary alluvium in much of the irrigated region of the Valley is locally under artesian pressure, and the water table aquifer in the overlying alluvium is a perched aquifer. The two aquifers are not hydraulically independent; however, there is sufficient permeability in the confining layer to permit interchange of waters. At some locations, the confining layer is apparently absent and there is direct hydraulic connection between the tributary alluvium and the cobble layer. A typical geologic cross-section of the area can be seen in Figure 6 which indicates the approximate lateral extent of the aquifer.

RESEARCH APPROACH

The inflow-outflow analysis reported by the U.S. Environmental Protection Agency (1971) showed that the Grand Valley was the largest agricultural source of salt loading per hectare of irrigated land in the Colorado River Basin. Consequently, the Grand Valley became the initial focus of research studies to evaluate the effectiveness of various agricultural salinity control measures for reducing the salt loading reaching the Colorado River.

Water entering the near-surface aquifers in the Valley become heavily laden with salts dissolved from the soils and aquifers of marine origin which occur extensively in the area. The primary source of these soils and aquifers is the Mancos



Legend
Fine Gravel
Silty Clay Loam Soils
Cobble Aquifer
Tight Clay (Discontinuous)
Mancos Shale Bedrock
N
Government Highline Canal
Stub Ditch
Price Ditch
Grand Valley Canal
Orchard Mesa
Mesa County Ditch
Colorado River
0 5 10 15
Scale in meters
0 20 40 60
Scale in feet
Vertical Scale
0
Scale 1 Kilometer
0
Scale 1 Mile
Horizontal Scale

Figure 6. A typical geologic cross-section in the Grand Valley, indicating the approximate areal extent of the cobble aquifer.

Shale formation which was formed as a result of the alternate advance and recession of the great inland seas once dominating the western United States. Since the water entering local aquifers comes mainly from irrigation channel seepage and deep percolation from excessive and inefficient irrigations, the emphasis of a salinity control program is to maximize the efficiencies of both the conveyance and farm water-use subsystems.

Canal and Lateral Lining

Aside from the numerous studies in the Grand Valley to evaluate local conditions, this effort, the Grand Valley Salinity Control Demonstration Project, was the first study conducted in the area to determine the effect of salinity management practices on conditions in the Basin. The project was funded on a matching basis by the Environmental Protection Agency in conjunction with the Grand Valley Water Users Association, Palisade Irrigation District, Mesa County Irrigation Company, Grand Valley Irrigation Company, Redlands Power and Water Company, and the Grand Junction Drainage District to further the development of pollution control technology in the Basin. Each of these entities had representatives on the Board of the Grand Valley Water Purification Project, Inc. (later renamed Grand Valley Canal Systems, Inc.), which was formed to contract with the Federal government to conduct this demonstration project. The primary objective of the initial project was to demonstrate the feasibility of reducing salt loading in the Colorado River system by lining conveyance channels to reduce unnecessary groundwater additions.

The project was composed of three study areas selected for their different characteristics commonly found in the Valley. Area I, shown in Figure 7, was chosen as an intensive study area in which the bulk of the investigation was to be conducted and also included most of the construction effort. This area was designated for detailed investigations regarding effects of conveyance linings on the water and salt flow systems in an irrigated area. The intensive study area was selected for its accessibility in isolating most of the important hydrologic parameters, but had the important advantage that it allowed five irrigation companies to participate in one unit. Area II was selected because it represented a different landform several miles west of Area I along a short section of the Grand Valley Canal where high seepage losses had resulted in a severe drainage problem. Area III was located along a section of the Redlands First Lift Canal, which is supplied from the Gunnison River and was selected to evaluate the effect of a different soil type and drainage condition.

The preconstruction and postconstruction evaluation of canal and lateral lining was based upon a hydro-salinity model having two basic subsystems, surface water and groundwater.

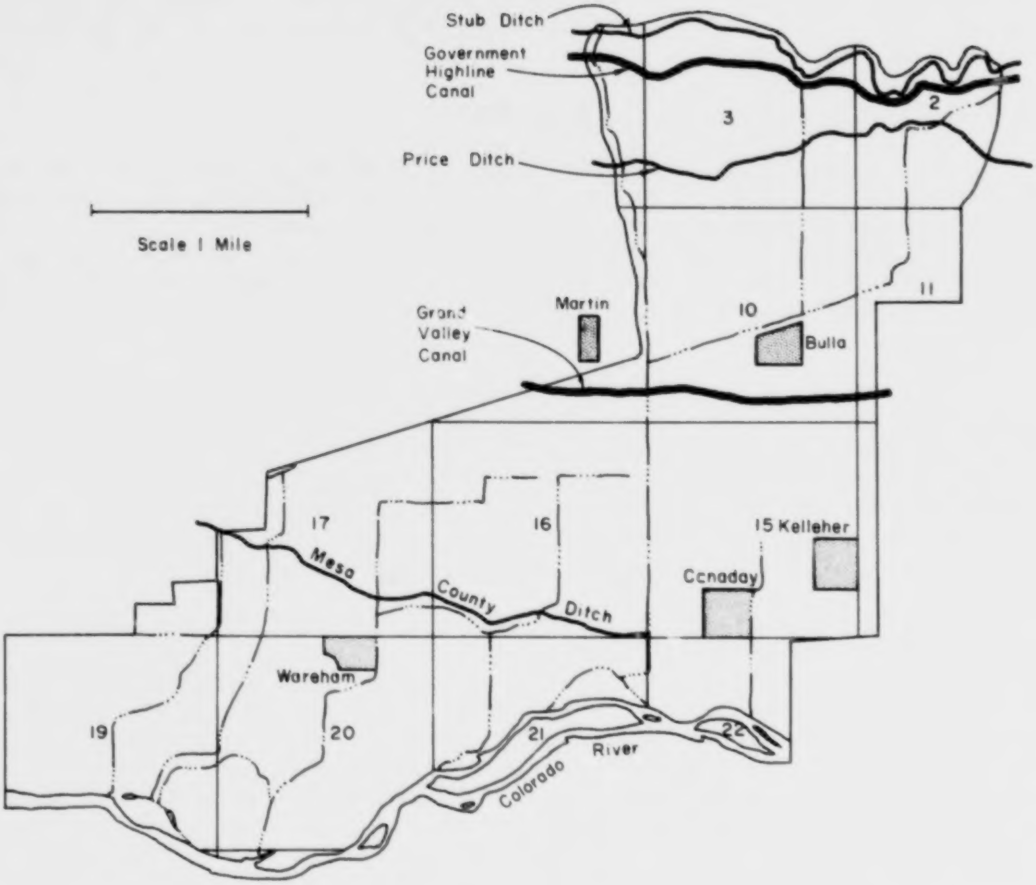

Stub Ditch
Government Highline Canal
3
2
Price Ditch
Scale 1 Mile
Martin
10
11
Grand Valley Canal
Bulla
17
16
15 Kelleher
Mesa County Ditch
Canaday
Wareham
19
20
21
22
Colorado River

Figure 7. Intensive study area for the Grand Valley Salinity Control Demonstration Project and location of irrigation scheduling and drainage study farms.

The study was conducted to collect and analyze sufficient data to define in detail both the water and salt flow systems (Skogerboe and Walker, 1972). This report also provides a summary of previous investigations concerned with irrigation and drainage in Grand Valley, as well as a history of irrigation development in the Valley. A complete land use inventory of the entire Grand Valley (Walker and Skogerboe, 1971) was undertaken (along with some sampling programs throughout the irrigated area to define lateral lengths, field head ditches, etc.) in order to allow the results from the intensive study area to be projected valley-wide.

Irrigation Scheduling and Drainage

The activities begun in 1968 to evaluate canal and lateral linings as salinity control measures demonstrated the need for further investigations concerning on-farm management practices. As a result, a second-and-third-phase program was undertaken to determine the feasibility of two farm management improvements--irrigation scheduling and field relief drainage--in controlling salinity.

Five fields in the demonstration area were incorporated into the second and third phases of the studies to represent a cross-section of agricultural practices in the Grand Valley. These farms, located in Figure 7 and described in Table 1, were included in an irrigation scheduling service implemented in the Valley by the local USBR office, thereby allowing the efforts of this investigation to be coordinated with the USBR.

Since the intensive study area is characteristically operated by small unit farmers and the soils are severely affected by the high-water table conditions, agricultural productivity is not presently sufficient to support most of the occupants, and many have outside jobs in local businesses or industry. One of the concerns of the investigators was in demonstrating the value of the irrigation scheduling service to these individual landowners. In addition, these lands were once among the Valley's most productive (at the turn of the last century) and a significant impetus could be generated locally in support of salinity control programs if such measures were effective in returning these lands to a high level of agricultural productivity.

During the second phase study, an effort was made to evaluate irrigation scheduling under various management conditions ranging from little or no improvements in on-farm irrigation practices to maximum use of the scheduling recommendations. Three of the farms, namely the Kelleher, Canaday, and Wareham farms, were included primarily as part of the third phase of this project involving field drainage, but were included in the scheduling program to yield a linkage between the two studies.

TABLE 1. DESCRIPTION OF FARMS IN THE DEMONSTRATION AREA INCLUDED IN THE 1973 IRRIGATION SCHEDULING AND DRAINAGE STUDIES.

Farm	Crop	Crop Acreage	Field Capacity	Wilting Point, %
Martin	Corn	9.2	22.3	10.7
Bulla	Barley	10.7	24.2	13.4
	Corn	15.0	23.9	12.1
Canaday	Barley	17.1	26.5	12.8
Kelleher	Oats	9.8	25.0	12.2
	Pasture	1.0	25.8	14.1
Wareham	Alfalfa	17.4	30.5	16.7
	Crested Wheatgrass	13.6	29.3	16.7

The two fields referred to as the Martin and Bulla farms were intensively studied to evaluate the potential for salinity control resulting from irrigation scheduling, along with the requirements for maximizing this potential in the Grand Valley with structural and nonstructural improvements in the irrigation system.

For the third phase study, irrigation practices and drainage problems were monitored on the Kelleher, Canaday, and Wareham farms during the 1972 irrigation season. Then, during the spring of 1973, a perforated plastic pipe drainage system was constructed on the Wareham farm. All three farms were then incorporated into the irrigation scheduling program during the 1973 irrigation season.

Soil Chemistry and Crop Yield Studies

Predicting Chemical Quality--

The hydro-salinity model developed under the first phase of this research program describes the present situation in the study area regarding water and salt flows. However, the only method for predicting the reduction in salts returning to the river through implementation of any salinity control measure(s) is by assuming a one-to-one relationship between water and salt. That is, if the subsurface return flow is reduced by 50 percent, the salt pickup is also reduced by 50 percent. In order to overcome this limitation, a project "Irrigation Practices, Return Flow Salinity, and Crop Yields" was initiated.

Three adjacent fields containing 9.3 hectares were leased for this study (Figure 8). The area was divided into 54 plots which were 30.5 meters by 30.5 meters in size, two plots which were 12.2 meters by 61 meters, two plots which were 12.2 meters by 91.4 meters, and five plots which were 12.2 meters by 152 meters. Each plot was used for a different replication of the crop, fertilizer and irrigation treatments. They were constructed so that each plot performed as a large lysimeter. A trench was excavated slightly into the shale along the lines dividing the plots, with the depth to shale varying from 1 to 6 meters, and the average being 3 meters. A plastic curtain was then placed vertically in the center of the trench to divide the individual plots. The lower edge of the curtain was "sealed" to the shale by backfilling to the original elevation of the shale with compacted clay. Consequently, the shale floor and plastic membrane walls act to create a box around each plot, with each plot serving as a large lysimeter.

The drainline encased in a gravel filter material was then placed at about the same elevation of the shale, inside the curtain, and continued around the periphery of the plot. Upon leaving the plot area, the water was transported via solid pipeline to a measuring station where water quality and quantity were monitored.

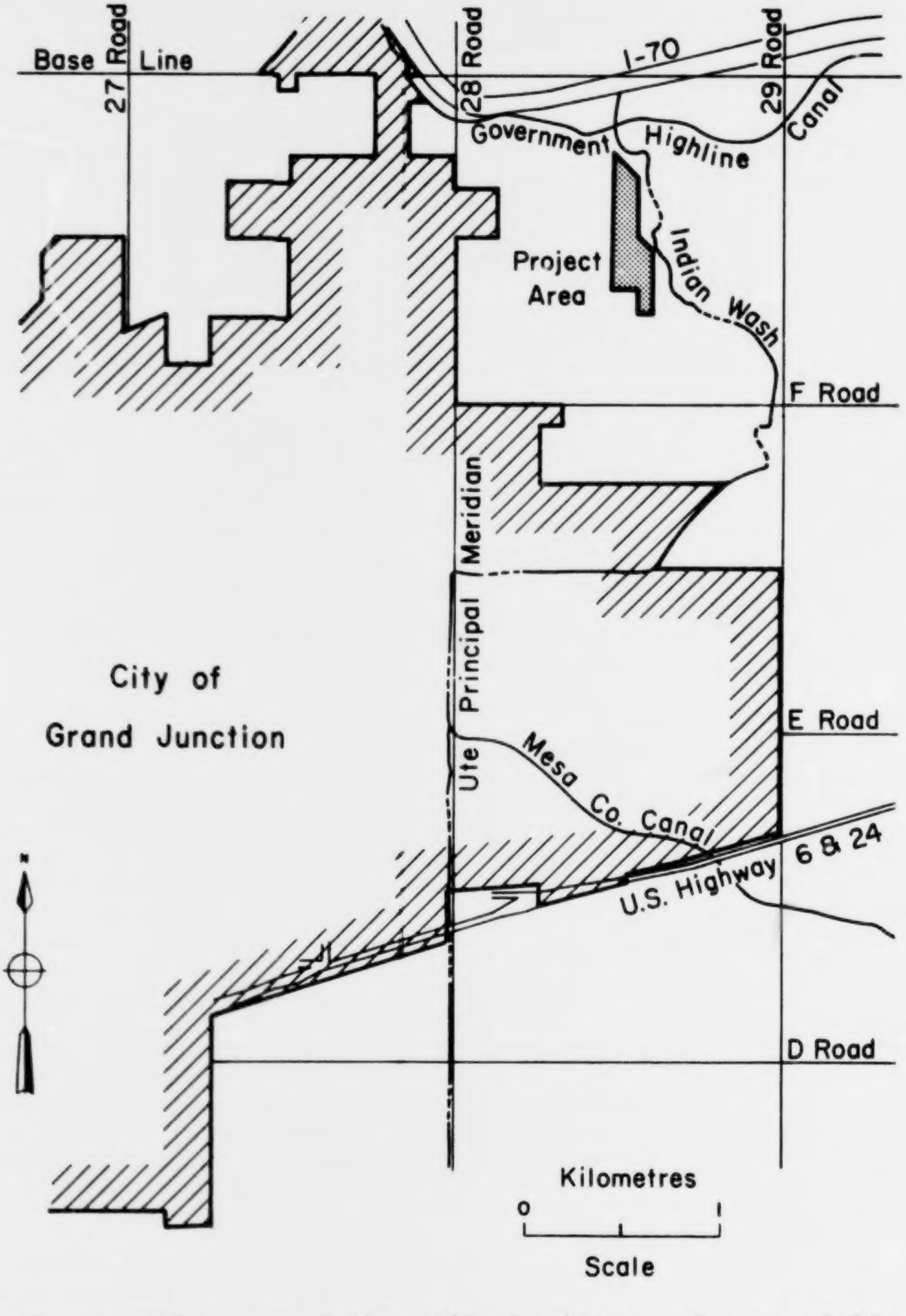

Base Line
27 Road
28 Road
29 Road
I-70
Government Highline Canal
Project Area
Indian Wash
F Road
Ute Principal Meridian
City of Grand Junction
E Road
Mesa Co. Canal
U.S. Highway 6 & 24
D Road
Kilometres
0
1
Scale

Figure 8. Location map of the soil chemistry and crop yields study area.

The irrigation system was designed to deliver water through a closed conduit to each plot and allow measurement of the flows onto each plot. Since furrow irrigation is used almost exclusively throughout the Valley, this method was employed in the experiments.

The crops that were grown consisted of corn, grass, alfalfa, and winter wheat, since these are the main crops grown commercially in the Valley (except the Jose Tall Wheatgrass, which was grown as a highly salt tolerant crop that could be used in reclaiming highly saline lands). By varying irrigation timing and amounts and nitrogen fertilizer levels on the different plots, and by monitoring quality and quantity of both inflow and outflow waters, the effects of these parameters on return flow salinity and crop yields were evaluated for corn and wheat.

A salt and water budget could be developed for each plot and compared to those developed for the other plots. From these data, equations could be developed to predict the variation in chemical quality (including ionic constituents) of the moisture movement through the soil profile, as well as the salt pickup resulting from movement of subsurface irrigation return flows. These results could then be combined with the hydro-salinity model to evaluate the effectiveness of various salinity control measures in reducing the salt load reaching the Colorado River (Skogerboe et al., 1978a).

Crop Yield Functions--

To determine the economically optimal allocation of irrigation water to a given crop, the relationship between the yield of the crop and its use of the supplied water must be known. Studies of this relationship, particularly those considering the grain yield (the reproductive organ) of the crop, have generally resulted in a curvilinear line of best fit being drawn through a scatter of data. More recent studies (including this research program) indicate that this scatter of data largely results from the time of occurrence of water deficits in relation to the stage of growth. Crops are far more sensitive to moisture stress during some stages (i.e., pollination in corn) than others. If a crop is supplied a seasonal quantity of water less than its potential requirements, exaggerated yield reduction could occur if the deficit occurs during periods of such sensitivity. The scatter in data can be considerably reduced, therefore, if deficits are so timed that they cause the least yield reduction for the given quantity of water supplied (Skogerboe et al., 1978b).

The research plots used in the soil chemistry studies were used to investigate the effects upon yield of stressing corn and wheat during the different stages of growth. The corn was differentiated in three subsequent growth stages. Stage I was from the emergence and establishment stage through the main period of vegetative growth preceding tasseling. Stage II was the pollination period from tasseling to the blister kernel stage, and Stage III was the grain filling period from blister kernel to physiological maturity. These growth stages coincide with those of Stewart et al. (1975), although some subjectivity is involved in the differentiation between growth stages.

Water was applied to the corn weekly during one, two or three of the growth stages, giving eight different treatments (Figure 9). Each treatment was replicated four times. The eight plots within a replication were grouped contiguously to provide approximately equal depth to shale within the replication.

These plots being watered within a growth stage were watered once a week with a net amount calculated to be slightly in excess of the crop requirements. Thus, in the early stages it was planned that the watered plots would receive approximately 40 mm per week, rising to 65 mm per week during the period of peak demand. Stressing during a particular growth stage was achieved by eliminating all irrigation from the stressed plots during that growth stage. Rainfall which fell during the growing season was light and infrequent, allowing a high degree of stress to be applied.

The winter wheat plots were similarly differentiated according to growth stage, although to a somewhat limited scale due to experimental work with the wheat not beginning until the spring following its winter dormancy. All plots were watered during the week beginning the 17th of May, when in the late boot stage; after which two growth stages were considered, the anthesis period and the grain filling period. Three plots received water only during the first stage (I-O), two plots received water only during the second stage (O-I), three plots received water during both stages, (I-I), and two plots received no water at all during both of these stages (O-O). Approximately 50 mm (net) of water was applied per week to those plots being irrigated.

Development of Technological Package

Economically feasible means of controlling salinity associated with irrigation return flows had been evaluated individually and independently in previous investigations. In order to extend these results to the formulation of comprehensive plans for controlling salinity on a large scale, it was necessary to describe the interrelationships which exist among the alternatives. Prior to this project, some limited evidence had indicated that the functions describing costs and effectiveness of specific salinity control measures were nonlinear. Therefore, if salinity control measures are not mutually exclusive, then an "optimal" salinity control strategy would consist of a combination

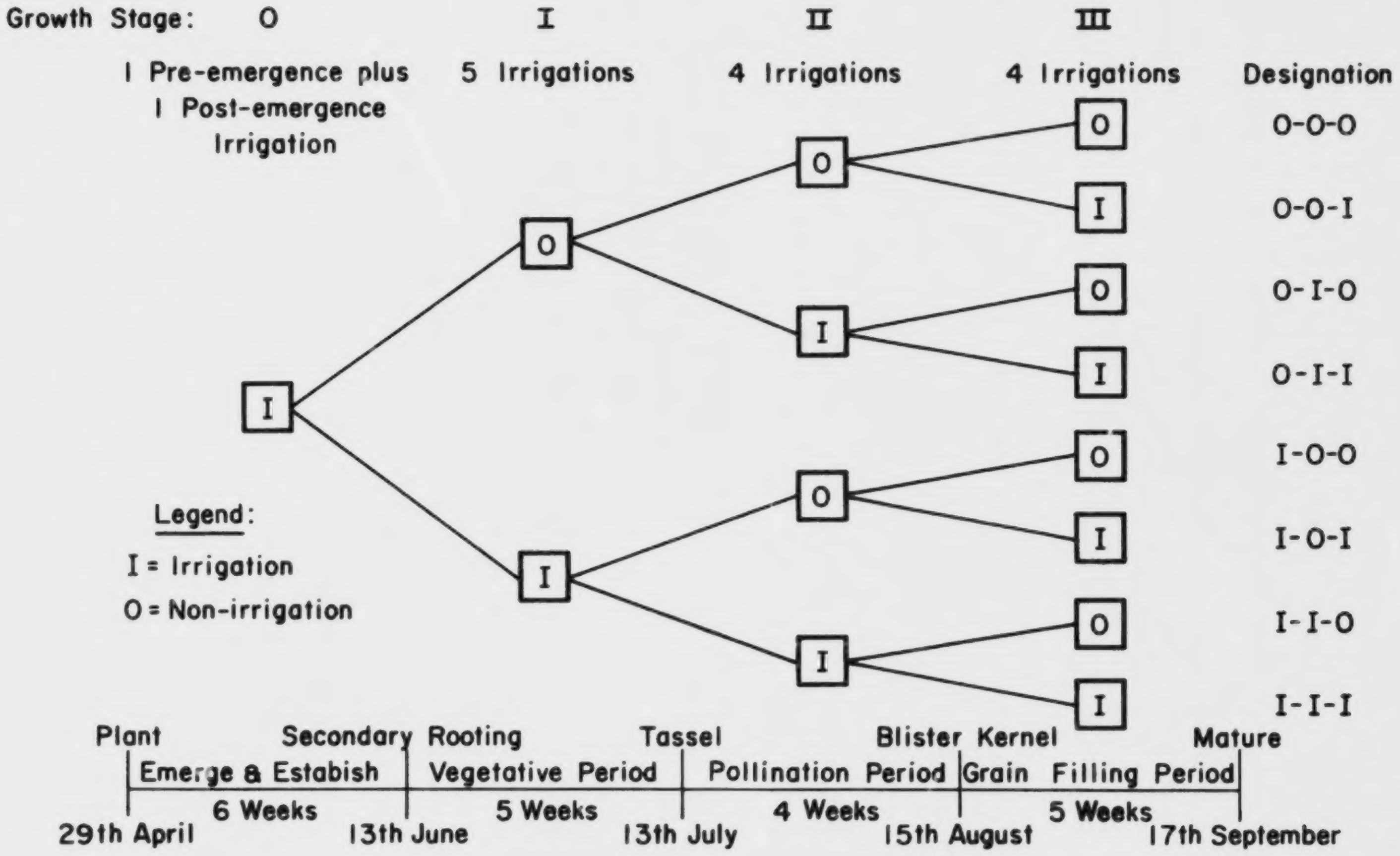

Growth Stage: O
I
II
III
1 Pre-emergence plus
1 Post-emergence
Irrigation
5 Irrigations
4 Irrigations
4 Irrigations
Designation
I
O
I
O
I
O
I
O
I
O
I
O
I
O
I
O-O-O
O-O-I
O-I-O
O-I-I
I-O-O
I-O-I
I-I-O
I-I-I
Legend:
I = Irrigation
O = Non-irrigation
Plant
Secondary Rooting
Tassel
Blister Kernel
Mature
Emerge & Estabish
Vegetative Period
Pollination Period
Grain Filling Period
6 Weeks
5 Weeks
4 Weeks
5 Weeks
29th April
13th June
13th July
15th August
17th September

Figure 9. Irrigation treatments for corn.

of several alternatives. The respective composition of such a strategy would depend on the relative magnitude of each hydrologic segment of an irrigated area. Thus, an important step in solving salinity problems was to investigate the nature of improvements incorporating several alternatives, or in simpler terms, assessing the impact of a "package" of salinity control measures.

The primary objective of this final demonstration phase was to show the advantages of implementing a "package" of technological improvements within the lateral subsystem. Although major emphasis was upon on-farm improvements, considerable improvements in the water delivery conveyances and some improvements in lowering high-water tables (drainage) were also required.

This demonstration phase utilized each of the salinity control measures previously evaluated in Grand Valley, with the additional use of various irrigation methods to demonstrate the complete package of salinity control measures. No single measure will adequately alleviate the salt load from an irrigated area, while a complete package of salinity control measures can be expected to reduce the salt load beyond the sum of each individual measure because of improvements in the operation and management of each lateral.

The intensive study area in the Grand Valley, which had been used for evaluating the effectiveness of canal and lateral lining, irrigation scheduling, and tile drainage in reducing the salt load entering the Colorado River, was also used for this demonstration project. In order to facilitate the continued participation by the irrigation interests in the Grand Valley, the laterals were selected to cover as many canals as possible. The final selection, as shown in Figure 10, had two laterals under the Government Highline Canal, one under the Price Ditch, three under the Grand Valley Canal, and three under the Mesa County Ditch. It should be pointed out that the lands served by the Government Highline Canal in the demonstration area are served under carriage contract with Mesa County Irrigation District (Stub Ditch) and the Palisade Irrigation District (Price Ditch). Therefore, all the irrigation entities in the demonstration area were involved directly in the project.

The laterals were selected to capitalize on previous work regarding canal and lateral lining, irrigation scheduling, and drainage studies. The selection of a lateral as a subsystem rather than an individual farm, had a tremendous advantage in allowing control of water deliveries at the lateral turnout. In this way, both the quantity of flow and the time of water delivery could be controlled, facilitating improved water management throughout the subsystem.

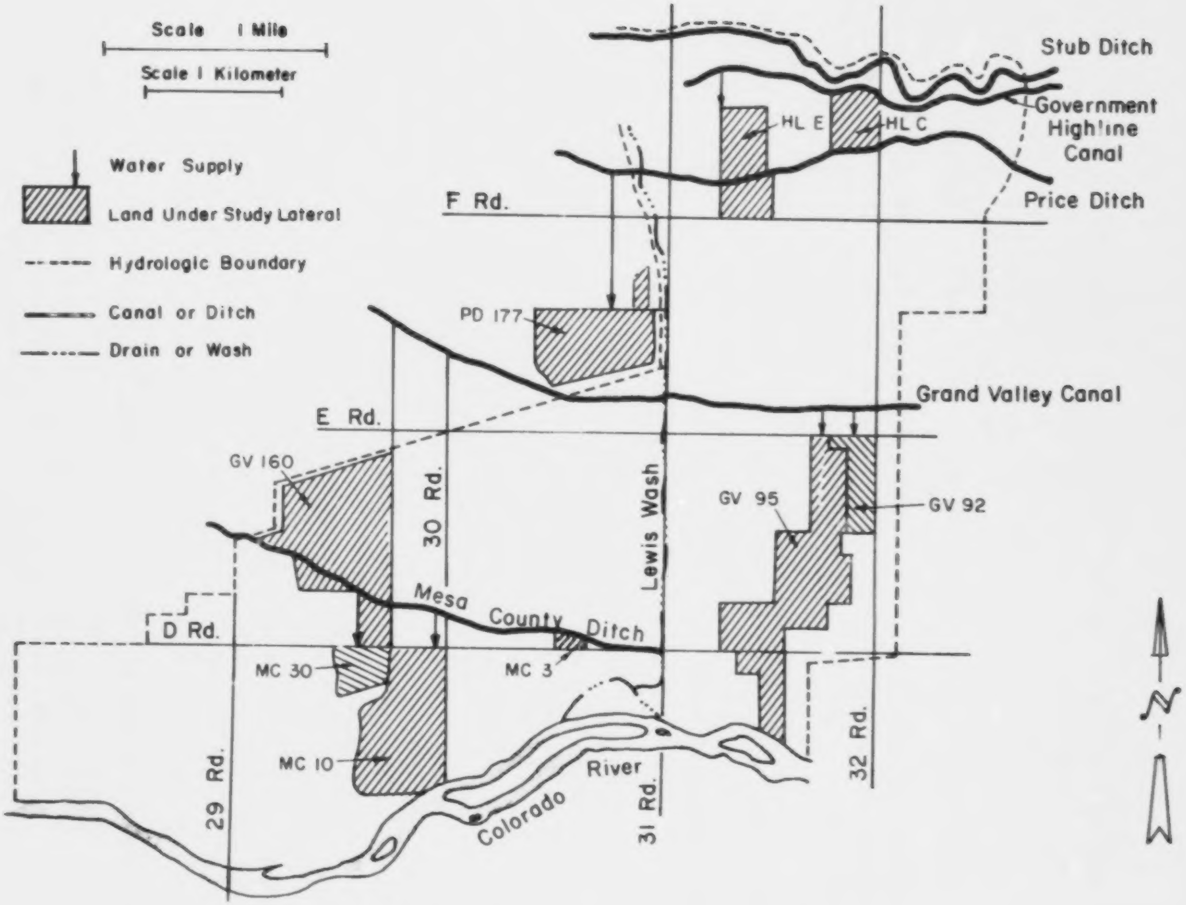

Scale 1 Mile
Scale 1 Kilometer
Water Supply
Land Under Study Lateral
Hydrologic Boundary
Canal or Ditch
Drain or Wash
Stub Ditch
Government Highline Canal
Price Ditch
HL E
HL C
F Rd.
PD 177
Grand Valley Canal
E Rd.
GV 160
30 Rd.
Lewis Wash
GV 95
GV 92
Mesa County Ditch
D Rd.
MC 30
MC 3
MC 10
29 Rd.
Colorado River
31 Rd.
32 Rd.
N

Figure 10. Location of the nine selected lateral subsystems incorporated in the project.

The experimental design for the preevaluation was primarily aimed at providing specific information for the 330.7 hectares (817 acres) undergoing treatment listed in Table 2. The field data collection program allowed the design of irrigation and drainage facilities and provided sufficient data to allow predictions of salinity benefits which resulted from each specific salinity control measure.

A variety of irrigation methods were demonstrated, including adjusting or "tuning-up" present irrigation methods being used in the study area. Considerable experience had been gained in improving the existing irrigation methods while evaluating irrigation scheduling as a salinity control measure in the Grand Valley. In addition, more advanced irrigation methods had been evaluated as to salinity benefits in the Grand Valley. The irrigation systems constructed under this project included automated farm head ditches, sprinkler irrigation, and trickle irrigation (Evans et al., 1978a, and Evans et al., 1978b).

Although the postevaluation included the monitoring of water and salts entering and leaving the demonstration area, the primary emphasis was the on-site evaluation of each specific salinity control measure. The on-site evaluation was then compared with the results of the total demonstration area hydrosalinity monitoring program. The concurrent EPA research project, "Irrigation Practices, Return Flow Salinity, and Crop Yields," which was also conducted in the Grand Valley, was utilized in developing the cost-effectiveness of each salinity control measure. The combined results of these two projects were extremely important in establishing the benefits to be derived from implementing a salinity control technology package.

A two-day "Field Days" was conducted during the third year of this project in the month of August, 1976, which was attended by approximately 800 people. This event was primarily directed toward the growers in the Grand Valley and secondly to irrigation leaders (mostly growers) throughout the Upper Colorado Basin. State and Federal agency personnel also attended. This was coupled with an irrigation equipment show and was cosponsored by the Colorado State University Cooperative Extension Service.

TABLE 2. FINAL SELECTION OF LATERALS INCLUDED IN PROJECT

Lateral Identification	Canal	Area		No.of Irrigators[5]
		Hectares	Acres	
HL C	Highline Canal	13.1	32.4	1
HL E[1]	Highline Canal	35.9	88.6	2
PD 177[1] [4]	Price Ditch	27.8	68.8	6
GV 92	Grand Valley Canal	24.3	59.9	6
GV 95 [2] [3]	Grand Valley Canal	79.1	195.7	13
GV 160	Grand Valley Canal	78.7	194.3	8
MC 3	Mesa County Ditch	3.7	9.0	1
MC 10[1]	Mesa County Ditch	54.0	133.4	9
MC 30[2]	Mesa County Ditch	14.1	34.7	1
	TOTAL	330.7	816.8	47

[1] These laterals were part of the earlier EPA funded canal and lateral lining study.

[2] This lateral was part of the earlier EPA funded field drainage study.

[3] This lateral consolidated an additional 70 acres from two other laterals.

[4] A portion of this lateral was included in the previous EPA funded irrigation scheduling program.

[5] An irrigator is defined as a person who farms more than one acre. In actuality, 89 persons are involved in the operation of this project.

SECTION 2

CONCLUSIONS

1) Of the 10 million metric tons of salt annually reaching the Lower Colorado River Basin, 600,000 to 700,000 metric tons are annually contributed by the Grand Valley. The salt load contribution from Grand Valley is the result of saline subsurface irrigation return flows reaching the Colorado River. The alluvial soils of Grand Valley are high in natural salts; however, the most significant salt source is the Mancos Shale formation underlying these alluvial soils which contain crystalline lenses of salt which are readily dissolved by the subsurface return flows.

2) The irrigation water supply is at least three times greater than the crop water requirements. Although much of this excess water returns to open drains as surface runoff, which has negligible impact upon the salinity in the Colorado River, there are still significant quantities of water that reach the underlying Mancos Shale formation, then pass into a near-surface cobble aquifer, where the water is displaced into the Colorado River. These subsurface return flows are the result of seepage losses from canals and laterals, and excessive deep percolation losses from overirrigation of the croplands.

3) The excessive irrigation water supplies are the result of early development of irrigation systems in Grand Valley. The Grand Valley Irrigation Company has the first right (earliest priority) to water on the Colorado River in the state of Colorado. During extreme drought years, only the Government Highline Canal has to reduce its diversions. However, the irrigable acreage under each system has been substantially reduced by the addition of roads, homes, stockyards, etc., and the water supply is applied to less acreage.

4) The irrigation companies usually terminate their responsibility to the irrigators at the turnout gates along the canals which discharge water into the laterals. Generally, the water users under each lateral are only informally organized, and the lack of flow measuring devices greatly hinders their ability to equitably distribute the waters.

5) The combination of geologic setting, early water rights that yield abundant irrigation water supplies, reduction in irrigated acreage, lack of responsibility of irrigation companies to individual water users, the almost complete absence of flow measuring devices along the laterals, and the low annual charges (costs) for irrigation water all contribute to the salinity problem.

6) The abundant water supply has also created waterlogging and salinity problems for farmers in Grand Valley. Abandoned irrigated lands and reduced agricultural productivity of the lower lands are visual evidence of these problems. Salt accumulations on the ground surface are visible at numerous places throughout the Valley.

7) Soil chemistry studies showed that the salinity concentration of the deep percolation losses were independent of the volume of deep percolation, because the concentration of salt below the root zone produces a saturated gypsum and lime condition which is relatively constant. Groundwater chemistry data also show that the concentration of salt in the cobble aquifer, although double the concentration of deep percolation immediately below the crop root zone, is still relatively constant owing to the solubility limits of the major salts. Thus, the salt loading due to irrigation return flow can be calculated from a knowledge of the water balance for the Grand Valley. The reductions in salt loading reaching the Colorado River will be directly proportional to reductions in subsurface irrigation return flows (seepage and deep percolation losses).

8) Based upon the field data collection program which was incorporated into a water balance analysis, the sources of subsurface return flow (and consequently salt loading) are: (a) canal seepage 23 percent; (b) lateral seepage 32 percent; and (c) deep percolation losses 45 percent.

9) The salinity control cost-effectiveness associated with each alternative improvement is the basis for determining the formulation of an implementation policy. Studies reported in the technical literature indicate that the salinity damages in the Lower Colorado River Basin range from $150 to $350 per metric ton per year when extended to the Grand Valley. Local benefits to the project such as increased crop yields, reduced irrigation system maintenance costs, increased land values and other factors were not evaluated as part of this report and are not included in the cost-effectiveness of the various alternatives.

10) Concrete slip form lining or low-head PVC plastic lining of laterals are almost equal in cost-effectiveness and can reduce salinity at substantially less cost than the $150/metric ton value. Concrete slip form linings offer the

advantages of easier and less frequent maintenance than pipelines, and they are more acceptable to local irrigators. Pipelines, on the other hand, are easier and more rapidly installed and can be installed by the farmer as part of his matching cost requirements.

11) Use of high-head PVC pipe (SDR 81 or greater) or concrete pipe is not a cost-effective alternative to concrete linings or low-head PVC and should be discouraged. Attendant problems with the use of low-head pipe can be overcome by giving particular attention to design and rigorous installation specifications.

12) Field head ditch lining by concrete slip form or gated pipe have comparable cost-effectiveness values, and while costing more than twice as much as lateral linings to remove a unit of salinity, they still cost considerably less than the $150/metric ton value.

13) Evaluation of alternative methods of irrigation implies that cropland evapotranspiration can be well estimated. Three empirical approaches were used in this study: (a) the Blaney-Criddle method; (b) the Jensen-Haise method; and (c) the Penman method. The Blaney-Criddle approach underestimated lysimeter data by about 40 percent on a seasonal basis; corrections in the temperature coefficient reduced this seasonal error to zero, but estimates were still substantially in error for monthly time periods. The Jensen-Haise approach overestimated seasonal evapotranspiration by approximately 5 percent with a 10-15 percent error during the early spring windy periods. The Penman approach was better than the Jensen-Haise method in estimating seasonal values, but was not better at approximating the seasonal distribution of evapotranspiration.

14) Irrigation scheduling by itself is not a significant salinity control alternative, but is a necessary part of any strategy for improved water management in order to maximize the effectiveness of physical improvements. Scheduling should be referenced to the areas of a field receiving the least amounts of water, and then related to the operation of the irrigation system so that the duration of a water application is equal to the time required to refill the "least watered" root zone areas. In sprinkler irrigation, the least watered or "critical" areas would be along the shortest diagonal distance between two sprinklers on adjacent laterals; whereas for surface irrigated systems, it is at the lower end of the field.

15) Improved agronomic practices can be effectively utilized in the irrigation scheduling program. Field experiments with corn and wheat in Grand Valley showed that irrigation could be halted before the crop reached physiological maturity, allowing the stored soil moisture to carry the crop through

to harvest. At least one irrigation can be eliminated, which would result in decreased deep percolation losses. This practice not only improves yields, but also allows the soil to be drier for harvest, allows better utilization of winter precipitation and retains more nutrients in the root zone, particularly nitrogen, for use by subsequent crops.

16) A common practice in the Grand Valley is to plant crops half way between two furrows and then irrigate to provide sufficient moisture for germination. This practice contributes significantly to deep percolation losses and can be inexpensively reduced by changes in cultural practices such as planting in or on the edge of a furrow. New furrows can be made at a later time when the crop has partially developed a root zone.

17) Furrow irrigation is the predominant method of water application in the Grand Valley. Existing application efficiencies [(available root zone storage/applied water) x 100] are about 64 percent. Strict adherence to the scheduling philosophy outlined in (14) above would result in application efficiencies of 85 to 90 percent, but this appears to be unrealistic without substantial investments in automation. The cut-back method of furrow irrigation was demonstrated in the Valley at about the same cost-effectiveness for controlling salinity as head ditch linings.

18) Border irrigation is applicable in the Grand Valley, but not presently accepted. Graded borders have approximately the same potential application efficiency as furrow irrigation, while the costs would be higher due to higher land leveling requirements. In addition, border irrigation requires more skilled labor and a higher degree of management than is presently available in the area.

19) Level borders offer potential for reducing salt loading if problems with soil crusting can be controlled. The level borders also require a high level of management capability and would be quite adaptable to automation.

20) Properly managed sprinkler systems offer a large potential for reducing salt loading from irrigation return flows. Solid-set systems are not presently cost-effective in the Grand Valley, whereas the less expensive moveable systems (side-roll, etc.) are very competitive in an on-farm salinity reduction program. Achievable application efficiencies for sprinkler irrigation are 85 to 95 percent depending on the level of management of the system.

21) Trickle irrigation is cost-effective for orchard crops and has the greatest potential for reducing return flow salinity from these areas. However, it can be applied to less than 10 percent of the Valley. Due to the large cost of these

systems, trickle irrigation has a much poorer cost-effectiveness than properly managed surface irrigation systems.

22) Since sprinkler and trickle irrigation methods are not controlled by soil properties, changing to these systems potentially would have a very large impact on reducing the salt loading from the early season irrigations. These early irrigations are responsible for more than 50 percent of the total annual salt load resulting from irrigation return flows in the Grand Valley.

23) A comparison of the cost-effectiveness relationships of the various irrigation system improvements indicates that head ditch linings, gated pipe, and/or automated cut-back furrow irrigation will reduce salinity for approximately $100-$110 per metric ton per year (i.e., one ton of salt will be eliminated from the Colorado River each year over the life of the improvements at an initial investment of $100-$110 for the first year's ton). A limit of 146,500 metric tons per year is amenable to this alternative. Sprinkler irrigation could be utilized to extend local salinity control to 171,000 metric tons per year, at a cost of more than $130 per ton. The maximum control would be achieved through massive conversion to trickle irrigation (227,000 metric tons per year) at a cost of about $200 per ton.

24) Comparison of on-farm salinity control methods on a cost-effectiveness basis in the Grand Valley indicates that these measures are second only to lateral linings in feasibility.

25) Canal linings reduce salt loading at unit costs ranging from $190 to $700 per metric ton of salt removed.

26) Desalting in conjunction with pump drainage can be expected to become feasible to reduce salt loading at approximately $320 per metric ton.

27) Field relief drainage is infeasible for agricultural salinity control at any cited figures for downstream detriments.

28) Cost-sharing programs are highly effective in attracting irrigators to participate in programs for improving the lateral and on-farm components of the irrigation system, provided adequate technical assistance is available. Allowing individual irrigators to use their labor to meet all or part of their matching cost requirements certainly contributed to the ease of accomplishing the goals of the demonstration project.

29) In Grand Valley, the jurisdiction of the irrigation companies does not include the laterals in most cases, so there are no formal arrangements for managing the irrigation water supply and settling disputes among water users. The informal organizational arrangements used for the lateral improvement program, although satisfactory on most of the laterals, resulted

in numerous problems on a few laterals as far as collecting required matching funds for the project, as well as some difficulties in implementing improved irrigation practices.

30) Water delivery and irrigation application systems can be designed so that the irrigation has to be efficient for continued operation. Also, strict influent controls of the quantity of water diverted to a field should result in efficient irrigation. Both of these alternatives require substantial technical assistance to the growers to be effective.

31) Individual on-farm improvements should be the result of individual negotiations between the irrigator and technical assistance personnel. However, there is a clear need to involve irrigators in all phases of salinity related improvements. Where irrigators participated in design decisions, the systems were not always the most efficient, but were certainly the most workable and flexible from the standpoint of the water users. Participation in the actual construction provided operational insight, understanding of neighbor needs, a pride in workmanship, and in some cases, a more rapid completion of the work than by contractual methods.

32) Proper water management requires a strong emphasis toward on-farm water control structures, especially flow measurement devices. This project utilized standardized means for determining water flow rates. All flow measurement devices were designed or selected to be read directly by the farmers without the use of printed tables.

33) A large amount of technical assistance is required in working with farmers in designing on-farm improvements that suit their individual needs, to negotiate the financial terms, construction of the improvements, and assisting the irrigator in the proper management of his new system.

34) The implementation of a lateral and on-farm improvements program will result in excess water being available for renting or leasing to water users upstream from the Grand Valley.

SECTION 3

RECOMMENDATIONS

As a result of this rather extensive research project, there are several recommendations which can be made concerning the implementation of a "total" salinity control program.

1) Implementation of an action salinity control program in the Grand Valley should consist primarily of lateral improvements (i.e., concrete slip form lining or low-head PVC plastic pipe) and on-farm improvements. The lateral improvement program, the on-farm program, and the irrigation scheduling program should be integrated into a single program which plans, constructs, and operates a combination of improvements moving from one lateral to the next. The design of the on-farm improvements should not be separate from the lateral improvements. The programs, therefore, should be handled by one federal agency, most likely the Soil Conservation Service (SCS) since they have had considerable experience in this subject area in the Grand Valley. In addition, due to the small sizes of the laterals, the design criteria of the SCS are adequate.

2) Concrete lining of the Government Highline Canal should be postponed until completion of basinwide studies on cost-effectiveness of salinity control alternatives in other irrigated areas. Also, a canal lining program should wait until sufficient feedback is obtained from the lateral and on-farm improvements program, so that an accurate assessment of reductions in lateral diversions can be made, in order to properly size the canal, rather than constructing a canal which would have a larger capacity than necessary.

3) The use of metering headgates is recommended for closed conduit flows. Propeller meters should not be used due to excessive problems with sediment and maintenance. Other methods such as a constant head orifice are not justified economically for the small increase in discharge measurement accuracy. Open channel flow should be measured with Cutthroat flumes rather than Parshall flumes because of cost and ease of installation.

4) The plan of improvement must include sufficient flow measurement structures throughout the lateral subsystem to facilitate equitable distribution of the water supplies and improved irrigation practices.

5) The use of high-head plastic PVC pipe, transite (asbestos-cement) or concrete pipe is not recommended for lateral lining, because they are not cost-effective when compared to low-head (50-foot) plastic pipe or trapezoidal slip form concrete lining.

6) For lateral improvement programs which require the collective action of the irrigators served by a lateral, there is a need to encourage the users to formally organize under the corporate laws of the State of Colorado that apply to irrigation, which will: (a) substantially facilitate contractual arrangements for lateral improvements; (b) provide a much simpler means of handling matching cost requirements; and (c) provide a better means of implementing a comprehensive water management program for each lateral.

7) The prevalent method of water application should remain furrow irrigation. Fields larger than 10 hectares (which are very few) should be encouraged to convert to mobile (side-roll, etc.) sprinkler systems, whereas the limited orchard area should utilize trickle irrigation.

8) Furrow irrigation system improvements should involve lining head ditches with slip form concrete or gated pipe. Automation of the head ditch system with cut-back, pump-back, or a combination of these two should be implemented.

9) Land leveling should not be implemented on a large scale since infiltration rates are generally low and slopes are comparatively high. Uniformity of water applications is not a serious problem under Grand Valley conditions when cut-back or pump-back systems are used.

10) Training materials should be developed to instruct farmers in the use of proper irrigation practices, motivate them to be efficient by illustrating the potential for yield increases and salt loading reductions, and demonstrate the feasibility of the salinity control program.

11) The success of any salinity control program rests finally with the degree of participation of the farmers themselves. Farmers who have made exceptional progress in improving their on-farm water management practices should be given special recognition. Adequate numbers of technical assistance personnel should be available to help the irrigators develop such proficiencies with their system and develop a higher level of water management. However, the existing levels of technical assistance personnel needed to work with farmers are insufficient, particularly trained manpower with on-farm water management experience. Thus, special training courses should also be prepared and given to these individuals.

12) Once the physical facilities are completed on a lateral, a program of "scientific" irrigation scheduling should be used to maximize the effectiveness of the physical improvements. The agency in charge of the on-farm and lateral lining program should be given responsibility for the irrigation scheduling program. The service should also include pesticides and fertilization scheduling assistance to the local growers. After a number of years, the irrigation scheduling program should be turned over to the Grand Valley Canal Systems, Inc. Revenues from water transfers can be used to pay for this service, or farmers can be charged for this service through their annual water cost assessment fees.

13) Efficient irrigation methods and practices should be designed and can be mandated or constructed by: (a) having the irrigation delivery and application systems designed so as to require highly efficient methods for their viable operation; and (b) using strict influent control standards for the quantity of water diverted for each acre. Both of these alternatives will require a large amount of technical assistance to effect the desired changes.

14) The implementation program should be monitored, evaluated, and continuously refined. This process will not only maximize the effectiveness of the Grand Valley Salinity Control Program, but will provide valuable information and experience for implementing irrigation return flow quality control programs in other areas of the West. An annual review of the program should be conducted with participation by all involved parties.

15) The State Engineer's Office should develop standards and criteria for beneficial use of irrigation water in Grand Valley, which will limit the farm water deliveries. In conjunction, influent standards should be used, with an initial standard being the present water duty. The success of an influent control approach is dependent upon: (a) use of numerous flow measuring devices; (b) adequate technical assistance for working with and advising farmers on improved irrigation practices and methods; and (c) availability of funds for making the necessary structural improvements.

16) State legislation should be enacted that would authorize the irrigation companies in Grand Valley to sell, rent or lease the excess water resulting from this salinity control program to water users upstream from Grand Valley. The revenues from such water transfers should be used to line the canals or make other structural improvements to the delivery system.

17) New industries which require further water development, such as energy complexes, and interbasin water transfers should be allowed to offset their salinity detriments (which are

primarily salt concentrating effects) by lining a sufficient length of the Grand Valley Canal or make other structural improvements in the irrigated areas.

18) Preliminary evidence suggests that irrigation of urban lawns, landscapes and parks may contribute approximately the same salt loading per hectare as agricultural water uses. Therefore, a salinity control program should be developed and tested for urban lawns, parks, golf courses, etc. in the Grand Valley.

19) The relative impact of on-farm improvements in reducing the salinity of the Colorado River ought to be considered throughout the Basin before plans are finalized for the Grand Valley. In other words, on-farm and lateral lining improvements in the Grand Valley, coupled with similar programs in other areas, may be more cost-effective than complete off-farm full-scale improvement programs (canal lining, desalting, drainage, etc.) in the Grand Valley. However, the lateral lining and on-farm improvement programs for the Grand Valley should be initiated immediately.

20) The ultimate level of salinity control decided upon for the Grand Valley should be evaluated in a basinwide context. The marginal costs of salinity control are linearly distributed and, therefore, other areas will be better sites for salinity control efforts than plans approaching full-scale control in the Grand Valley. Consequently, the Grand Valley studies of on-farm improvements should be extended to other irrigated areas in the Upper Colorado River Basin.

SECTION 4

GRAND VALLEY HYDRO-SALINITY SYSTEMS

In the 1960's, a concerted effort was undertaken to identify the sources of salinity in the Colorado River Basin. The Federal Water Pollution Control Administration, then within the Interior Department, utilized United States Geological Survey (USGS) stream gaging data as well as an extensive water quality sampling program to identify the major salt contributors in the Basin (United States Environmental Protection Agency, 1971). The Grand Valley in western Colorado was described as one of the largest agricultural sources of salinity (about 18 percent of the total Upper Basins' agriculturally related contribution), and it subsequently became the site for the first studies to evaluate field-scale salinity control measures.

The early studies identified the Grand Valley as a major problem area by mass balancing water and salt flows into and out of the Valley region. Similar investigations by Iorns et al. (1965) and Hyatt et al. (1970) produced supportive results, although a substantial variability in the specific nature of the Grand Valley salinity problem emerged. Since that time, a great many individual calculations describing the Valley salt loading and the respective components have been made, but very little agreement existed until early 1977 when most studies were completed. Although some variability still exists among the various investigative groups, the differences are sufficiently close that they become relatively unimportant in evaluating optimal salinity control policies for the Valley.

Problem Identification

The procedures for delineating the water-salt flow system in an irrigated area are collectively termed hydro-salinity budgeting, or hydro-salinity modeling, since computers are generally needed to handle the large number of necessary calculations. In the Grand Valley, the composition of this system has been extensively investigated at various levels of sophistication. As the salinity investigations were continued, refinements in the Valley's basinwide impact have been made and verified. Interestingly, the research evolution in the Grand Valley case study suggests a fairly sound approach for other areas as well.

Remedying irrigation return flow quality problems can be divided into four logical steps. First, the magnitude of the problem and the downstream consequences must be identified in relation to the irrigated area's individual contribution to the problem. In this way, the most important areas can be delineated for further consideration, thereby making the most cost-effective use of available personnel and funding sources. As noted previously, the inflow-outflow analysis by EPA (1971) led to the conclusion that initial research efforts should concentrate in the Grand Valley. Next, the components of the problem must be segregated. In most large areas, the costs of studying the entire system are prohibitive, so smaller "sampling" studies are conducted (the demonstration area) from which projections are made to predict the behavior of the entire area. The third step is to evaluate management alternatives on a prototype scale in order to assess their cost-effectiveness and develop a sensitivity concerning the capability for implementing such technologies. And finally, if the measures which can be applied are effective in reducing salinity, are economically feasible, and are acceptable to the farmers, the final step is the actual application, or implementation, of the technologies in order to alleviate the water quality problem.

The Grand Valley was identified as an important agricultural source of salinity in the Colorado River Basin through a series of analyses involving mass balance of the Valley inflows and outflows. Iorns et al. (1965) evaluated stream gaging records for the 1914 to 1957 period, concluding that the net salt loading (salt pickup) from irrigation in the Valley ranged from about 450,000 to 800,000 metric tons annually. This range of numbers has been generated independently by Hyatt et al. (1970), Walker (1970), Skogerboe and Walker (1972), Westesen (1975), and the USGS (1976). More recent consideration of data by the writers and others indicates a long-term salt pickup rate between 600,000 to 700,000 metric tons/year. This figure is now generally accepted by the various research groups and action agencies involved with the Grand Valley salinity investigations.

The fact that the Valley's salinity contribution has been such a disputed figure over the last few years exemplifies the importance of establishing the total Valley contribution. In areas like the Grand Valley, where the total impact is only 5 to 8 percent of the river inflows or outflows, the impact of irrigation must be established using statistical analyses of the available data. However, the natural variability can cause serious errors in conclusions regarding salt pickup if not tempered by other data and analyses. For example, a major problem in early investigations was deciding how much of the inflow-outflow differences was due to natural runoff from the surrounding watershed. Because of the meager precipitation locally, the writers assumed the natural salt contribution would be negligible. This conclusion was later substantiated partially by Elkin (1976) who estimated an upward limit for the natural contribution of about 10 percent of agricultural sources.

Segregating the Irrigation Return Flow System

In the Grand Valley, as in numerous other irrigated areas, water is supplied to the cropland in a canal and lateral conveyance system. Water is diverted from the Colorado and Gunnison Rivers into three major canals: (a) the Government Highline Canal; (b) the Grand Valley Canal; and (c) the Redlands Power Canal. These large canals in turn supply the smaller canals and ditches as listed in Table 3.

TABLE 3. CANALS SERVED BY THE MAJOR CANALS IN GRAND VALLEY

Government Highline Canal	Grand Valley Canal	Redlands Power Canal
Stub	G.V. Mainline	Redlands #1
Price	G.V. Highline	Redlands #2
Orchard Mesa Power	Mesa County	
Orchard Mesa #1	Kiefer Extension	
Orchard Mesa #2	Independent Ranchmen's	

A description of the hydraulic characteristics of these canals and ditches is given in Table 4, based on information provided by the USBR. From the canals and ditches, water is diverted into the small, largely earthen laterals leading to the individual fields. This lateral system of approximately 600 kilometers of ditch carrying from 0.06 - 1.0 m^3/sec. A frequency distribution of the lateral lengths based on data provided by the USBR (1976b) indicated that the average length is about 400 meters, with an average capacity of about 0.10 m^3/sec.

Nearly all farmers in the Valley apply water using the furrow irrigation method. The Soil Conservation Service (SCS) inventory (1976) of the irrigation system indicates over 9,000 individual fields in the Valley having a wide range of widths, slopes and lengths. The typical field is 140 meters wide, 160 meters long, with a slope (toward the south generally) of 1.125 percent. A frequency distribution of field acreages showed the typical field encompassing a little more than 2 hectares. Calculating the length of unlined field head ditches based on the SCS data indicates a total unlined length of 1300 kilometers (1640 km total).

Irrigation water is applied to approximately 25,000 hectares during the course of a normal irrigation season (Walker and Skogerboe, 1971). This acreage has been substantiated by the recent SCS inventory and generally accepted by the other agencies.

TABLE 4. HYDRAULIC CHARACTERISTICS OF THE GRAND VALLEY CANAL AND DITCH SYSTEM

Name	Length (km)	Initial Capacity (m^3/sec)	Terminal Capacity (m^3/sec)	Initial Perimeter (m)
Government Highline Canal	73.70	16.99	0.71	19.19
Grand Valley Canal	19.80	18.41	14.16	16.67
Grand Valley Mainline	21.70	7.08	0.71	13.86
Grand Valley Highline	37.00	8.50	3.96	12.62
Kiefer Extension of Grand Valley	24.50	3.96	0.71	7.25
Mesa County Ditch	4.00	1.13	0.06	6.67
Independent Ranchmen's Ditch	17.40	1.98	0.85	3.17
Price Ditch	9.50	2.83	0.28	7.27
Stub Ditch	11.30	0.85	0.11	2.94
Orchard Mesa Power Canal	3.90	24.07	24.07	18.20
Orchard Mesa #1 Canal	24.10	3.12	0.17	6.46
Orchard Mesa #2 Canal	26.10	1.98	0.17	3.58
Redlands Power Canal	2.90	24.07	24.07	16.88
Redlands #1 & #2 Canals	10.80	1.70	0.06	3.95

Based upon lysimeter data reported by Evans et al. (1978a), the weighted average consumptive use demand by the irrigated portion of the area equals about 0.745 meters per season. A breakdown of the individual consumptive uses in the Valley is given in Table 5.

TABLE 5. CONSUMPTIVE USE ESTIMATED FOR THE GRAND VALLEY

Consumptive Use	Volume in ha-m	Depth in Meters
Open water surface evaporation and phreatophyte use[1]	3,450	0.138
Open water surface evaporation and phreatophyte use[2]	8,400	0.336
Cropland[3]	18,600	0.745
TOTAL	30,450	1.219

[1] adjacent to river
[2] along canals and drains
[3] approximate area of 25,000 ha

The irrigation return flow system in the Valley may be divided according to whether or not the return flows are surface or subsurface flows. Surface flows occur as either field tailwater or canal, ditch, and lateral spillage. Subsurface flows include canal and ditch seepage, lateral seepage, and deep percolation from on-farm applications (deep percolation in this sense to include head ditch and tailwater ditch seepage).

Canal and Ditch Seepage--

Since the early 1950's, five major seepage investigations of the major canals and ditches have been conducted (Skogerboe and Walker, 1972 and Duke et al., 1976). Although seepage rates have been noted over a wide range, some representative rates are presented for the 14 canals listed in Table 6, which in turn, have been used to compute the seepage volume for each canal and ditch. In the Grand Valley, the total canal seepage is estimated to be approximately 3,700 ha-m per year.

The seepage rates vary for each canal. The writers, using published data, applied the trends to the Grand Valley Canal, the Orchard Mesa System, and the Redlands System where data are few. The seepage rate from the Grand Valley Canal is assumed to be substantially lower than the value listed for the Government Highline Canal, even though both have similar capacities, because of the high-water table conditions surrounding the Grand Valley Canal along much of its length. The overall differences in the Valley budgets as summarized by Walker et al. (1977) and Kruse (1977) can be largely attributed to the differences in assigning seepage rates. The latter data reflect an approximately uniform application of the Government Highline Canal seepage rates.

Lateral Seepage--

Tests reported by Skogerboe and Walker (1972) and Duke et al. (1976) indicate seepage losses from the small ditches comprising the lateral system probably average about 8 to 9 ha-m/km/year in the Grand Valley. Thus, for the 600 km of small laterals, the total seepage losses are approximately 5,300 ha-m annually. Combined lateral and canal seepage is, therefore, approximately 9,000 ha-m annually.

On-Farm Deep Percolation--

Numerous studies in recent years have attempted to quantify deep percolation from on-farm water use. Skogerboe et al. (1974a, 1974b) estimated these losses (including head ditch and tailwater ditch seepage) to be about 0.30 ha-m/ha. Duke et al. (1976) estimated these losses, independent of on-farm ditch seepage, to be 0.15 ha-m/ha. Minutes of the Grand Valley Salinity Coordinating Committee show on-farm ditch seepage to be 0.12 ha-m/ha (Kruse, 1977). Combining the figures given by Duke et al., (1976) with Kruse (1977) gives a total on-farm subsurface loss of 0.27 ha-m/ha. Given the large number of fields tested by various investigators, total on-farm seepage and deep percolation losses are probably about 7,500 ha-m per year.

TABLE 6. SEEPAGE DATA FOR THE FOURTEEN MAJOR CANALS IN GRAND VALLEY

Name of Canal or Ditch	Days in Operation	Seepage Rate $m^3/m^2/day$	Seepage Volume ha-m
Government Highline	214	0.091	1,653
Grand Valley	214	0.045	291
Grand Valley Mainline	214	0.061	251
Grand Valley Highline	214	0.061	516
Kiefer Extension	214	0.061	160
Mesa County	214	0.061	24
Independent Ranchmen's	214	0.061	60
Price	214	0.061	60
Stub	214	0.061	30
Orchard Mesa Power	365	0.076	195
Orchard Mesa #1	214	0.076	160
Orchard Mesa #2	214	0.076	104
Redlands Power	365	0.065	116
Redlands 1 & 2	214	0.137	80
			3,700

Canal Spillage and Field Tailwater--

The operational wastes and field tailwater are difficult to define because, first, they do not generally create problems associated with salinity degradation, and second, data regarding these flows are sparse. Skogerboe et al. (1974a) listed field tailwater as 43 percent of field applications, whereas Duke et al. (1976) reported estimates of field tailwater and canal spillage or administrative wastes which were 18 percent and 35 percent, respectively. Estimates of spillage and tailwater by the USBR were slightly smaller than the authors' estimate. Using the 43 percent figure for field tailwater and the 18 percent figure for canal spillage yields about 37,000 ha-m per year for field tailwater and spillage.

Aggregating the data presented previously with inflow-outflow records in the vicinity of Grand Valley gives a clear picture of how the irrigation system relates to the overall hydrology (Figure 11). The flow diagram is particularly helpful in visualizing the relative magnitude of the irrigation return flows from the agricultural area in comparison with the flow in the Colorado River.

Identifying the Salinity Contribution

The salinity contribution of the Grand Valley hydrosalinity system can be developed in a number of ways.

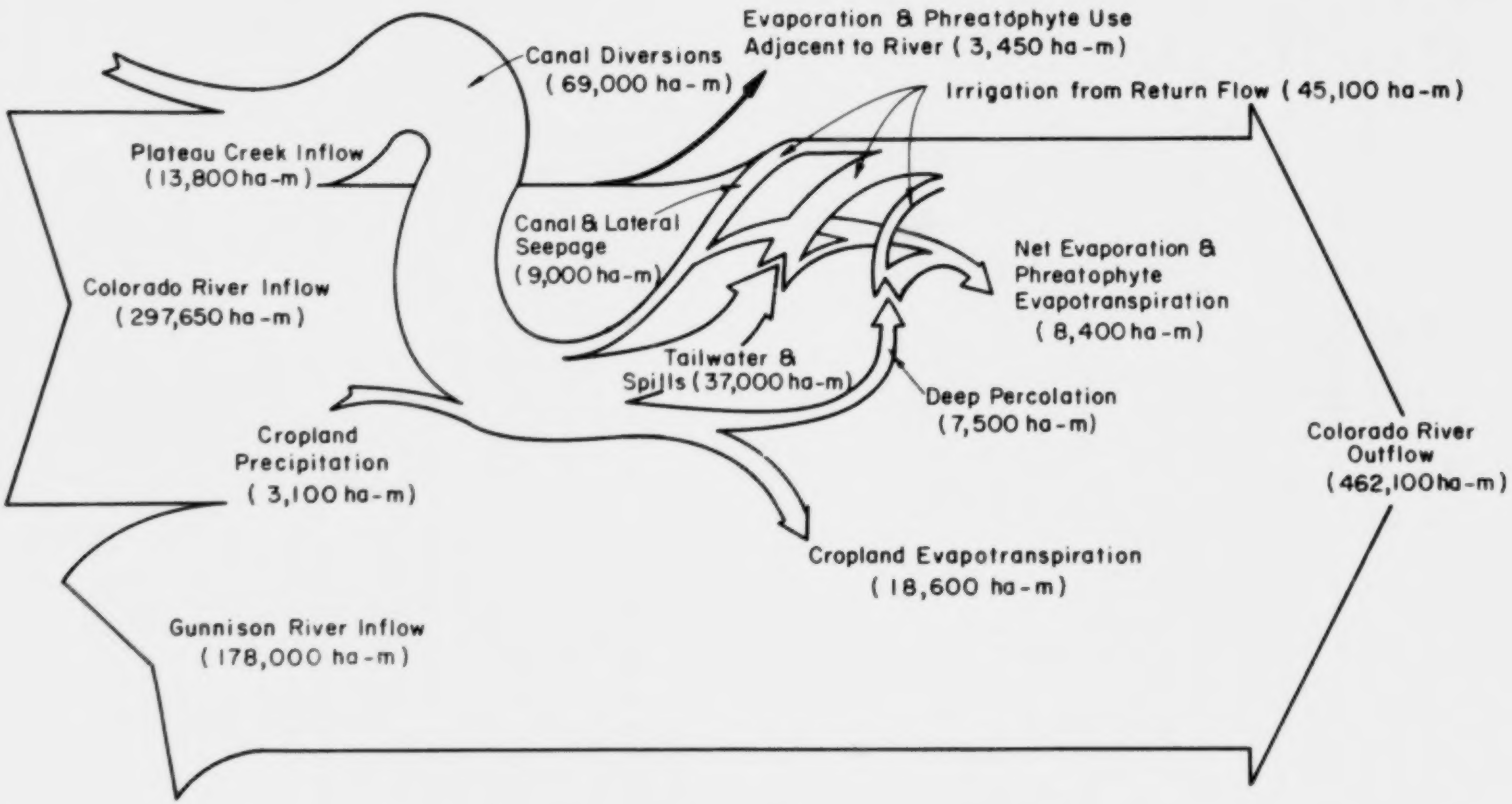

Canal Diversions
(69,000 ha - m)
Evaporation & Phreatophyte Use
Adjacent to River (3,450 ha -m)
Irrigation from Return Flow (45,100 ha -m)
Plateau Creek Inflow
(13,800 ha -m)
Canal & Lateral
Seepage
(9,000 ha -m)
Net Evaporation &
Phreatophyte
Evapotranspiration
(8,400 ha -m)
Colorado River Inflow
(297,650 ha -m)
Tailwater &
Spills (37,000 ha -m)
Deep Percolation
(7,500 ha - m)
Cropland
Precipitation
(3,100 ha - m)
Colorado River
Outflow
(462,100 ha -m)
Cropland Evapotranspiration
(18,600 ha - m)
Gunnison River Inflow
(178,000 ha -m)

Figure 11. Mean annual flow diagram of the Grand Valley hydrology.

For example, if the annual salt pickup is divided by the volume of groundwater return flow (630,000 tons/8,100 ha-m), the average concentration of the return flow due to salt pickup can be determined (7,800 m/ℓ). Data reported by Skogerboe and Walker (1972) indicated an average groundwater salinity of 8,000 to 10,000 mg/ℓ (average of 8,700 mg/ℓ), and, if the irrigation water salinity is 500-1,000 mg/ℓ, these figures agree quite closely.

The USGS and others have recently measured surface drainage return flows at selected areas in the Valley. These data indicate an average salinity of about 4,000 mg/ℓ. Thus, as Duke et al. (1976) pointed out, if all return flows were through the drainage channels and phreatophyte consumptive use was not considered, the calculation of salt pickup would result in an estimated valley-wide contribution of approximately 660,000 tons. Consequently, the two salt loading figures, as predicted by inflow-outflow mass balancing and calculations using local data, are sufficiently close to be confident in the values. Based on the figures pointed out in these preceding paragraphs, the salt loading due to irrigation in the Grand Valley can be segregated as follows:

1) Canal and Ditch Seepage	23 percent
2) Lateral Seepage	32 percent
3) On-farm Losses	45 percent.

Summary

At the time of this writing, there are two principal hydro-salinity budget estimates for the Grand Valley as mentioned previously. In various meetings and conferences, the differences have been noted and the essential areas of disagreement identified. The writers believe an examination of the budgets prove useful. Tabular budgets of the Grand Valley water and salt volumes are presented in Tables 7 and 8. It should be noted that the basis of the Kruse (1977) estimate has been expanded to be congruent with the analyses of Walker et al. (1977).

Probably no other issue has been considered more among the several research and planning groups associated with the Grand Valley than the net salt loading from the Valley. This figure is central to any salinity study because it defines the boundaries within which each segment of the agricultural hydrology must fit. By subtracting the salt carried in the irrigation water supplies from the volume of subsurface and drainage return flow, the net agricultural contribution can be delineated in metric tons annually as listed in Table 9.

The reader will note that the essential differences lie in two areas: (a) canal seepage; and (b) deep percolation.

TABLE 7. MEAN ANNUAL GRAND VALLEY WATER BUDGET (ALL UNITS IN HECTARE-METERS)

	1/	2/
River Inflows		
Plateau Creek	13,800	13,800
Colorado River nr. Cameo	297,650	297,650
Gunnison River nr. Grand Junction	178,000	178,000
	489,450	489,450
Evaporation and Phreatophyte Use (net)	3,450	2,950
Canal Diversions		
Lateral Diversions	52,900	54,100
Seepage	3,700	7,620
Operational Wastes	12,400	22,100
	69,000	83,820
Lateral Diversions		
Seepage	5,300	6,100
Field Tailwater	24,600	25,140
Cropland Consumptive Use	18,600	19,100
Cropland Precipitation	-3,100	-3,100
Deep Percolation	7,500	6,860
	52,900	54,100
Irrigation Return Flows (Subsurface		
Canal Seepage	3,700	7,620
Lateral Seepage	5,300	6,100
Deep Percolation	7,500	6,860
Phreatophyte Withdrawals (net)	-8,400	-8,400
	8,100	12,180
Irrigation Return Flows (Surface)		
Operational Wastes	12,400	22,100
Field Tailwater	24,600	25,140
	37,000	47,240
River Outflows		
Colorado River at Colorado-Utah State Line	462,100	462,100

1/ Walker et al. (1977)

2/ Kruse (1977)

TABLE 8. MEAN ANNUAL GRAND VALLEY SALINITY BUDGET (ALL UNITS IN METRIC TONS)

	1/	2/
River Inflows		
Plateau Creek	62,600	62,600
Colorado River nr. Cameo	1,352,600	1,352,600
Gunnison River nr. Grand Junction	1,371,700	1,371,700
	2,786,900	2,786,900
Canal Diversions		
Lateral Diversions	301,100	307,900
Seepage	21,100	43,400
Operational Wastes	70,600	125,800
	392,800	477,100
Lateral Diversions		
Seepage	30,200	34,700
Field Tailwater	140,000	143,100
Deep Percolation	130,900	130,100
	301,100	307,900
Irrigation Return Flows (Subsurface)		
Canal Seepage	163,200	268,500
Lateral Seepage (adjusted for	232,200	231,700
Deep Percolation salt pickup)	416,800	368,000
	812,200	868,200
Irrigation Return Flows (Surface)		
Operational Wastes (0 pickup)	70,600	125,800
Field Tailwater (0 pickup)	140,000	143,100
	210,600	268,900
Natural Diffuse Sources	30,000	72,600
River Outflows		
Colorado River at Colorado-Utah State Line	3,445,900	3,518,500

1/ Walker et al. (1977)

2/ Kruse (1977)

TABLE 9. SUMMARY OF MEAN ANNUAL SALT PICKUP IN METRIC TONS FOR AGRICULTURAL SOURCES IN THE GRAND VALLEY

	Walker et al. (1977) (1)	Kruse (1977) (2)	Ratio (2)/(1) (3)
Canal Seepage	142,100	225,100	1.58
Lateral Seepage	202,000	197,000	0.98
On-Farm Ditch Seepage	95,000	103,500	1.09
Deep Percolation	190,900	129,800	0.68
	630,000	655,400	1.04

The difference in canal seepage can be attributed solely to the assignment of seepage losses to respective conveyances whereas the deep percolation differences reflect the fact that both budgets were developed from extending data collected at different sites. The relative confidence in each study is about equal and the interested reader may review the technical reports if he chooses to examine this issue further. In a realistic sense, however, these differences are relatively unimportant, as will be demonstrated in later sections.

SECTION 5

TECHNOLOGICAL ALTERNATIVES FOR SALINITY CONTROL

IDENTIFICATION OF POTENTIAL SOLUTIONS

Prevention or control of water quality degradation due to irrigation return flow is both difficult and expensive to achieve. Potential solutions and control measures involve physical changes in the system, which can be brought about by constructing improvements to existing systems or by placing new institutional influences upon the system, or a combination of both. Since irrigation return flow is an integral part of the hydrologic system, control measures for managing the return flow from an irrigated area must be compatible with the objectives for water resource management and development in the total system (Skogerboe and Law, 1971).

This section is presented to outline the potential technological solutions to the irrigation return flow problem in the Grand Valley. These solutions have been classified into three groups: (a) improving water conveyance, including canals and laterals; (b) on-farm water management; and (c) water removal, including drainage and desalting. These groups conform to the three subsystems in an irrigation system; namely, water delivery, on-farm water use, and water removal (Skogerboe and Law, 1971).

Water entering the near-surface aquifers in Grand Valley displaces highly mineralized waters from these aquifers into the Colorado River. In any area where the water is in prolonged contact with soil, the concentration of mineral salts tends toward a chemical equilibrium with the soil. In Grand Valley, as in many other areas, high equilibrium salinity concentrations are known to exist in the near-surface aquifer. The key to achieving a reduction in salt loading is to lower the groundwater levels, which will result in less displacement of water from the aquifer into the Colorado River. The most effective means for lowering groundwater levels is to reduce the source of groundwater flows, which can be accomplished by reducing seepage through canal and lateral lining or by reducing deep percolation losses resulting from excessive irrigation by improved on-farm water management practices. Since a leaching requirement is a necessary part of local irrigation, some deep percolation losses can be expected under the most efficient irrigation practices. Therefore, relief tile drainage systems are also realistic salinity control alternatives when deep percolation and seepage losses, which have lower salinity concentrations than flows in the lower reaches of the groundwater system, can be intercepted and removed before equilibrium concentrations are reached. Also, drainage systems, either tile or pumping, must be considered in combination with desalting, along with the other adaptable salinity control measures.

IMPROVING WATER DELIVERY

Water is a surplus commodity in the Grand Valley because of its excellent water right priorities and the construction of homesteads, roads, and urban complexes have reduced the original irrigated acreage about 30 to 40 percent. Thus, instead of the originally developed 1.76 ha-m/ha water duty, there is now a diverted supply of about 2.74 ha-m/ha. The results are threefold. First, the history of development in the western United States has always shown water to be a valuable commodity to an area since the rights not historically diverted are subject to abandonment. The Grand Valley irrigation authorities have felt they must divert their rights for fear of losing them. In short, it is not the practice of agriculture to be wasteful, but the laws regulating the use of water dictate that a user either be wasteful or give up a valuable right. The second result is that there is no incentive to manage water efficiently because it is cheap and plentiful. And finally, most irrigation system improvement programs are initiated to reduce losses because supplies are short or to reduce maintenance. In the Grand Valley, the abundance of low cost water has economically discouraged efforts to reduce losses, so the existing system remains largely earthen channels.

The salinity associated with the conveyance system is attributable directly to seepage losses. Indirectly, rehabilitation and improved operation, management, and maintenance of the network of canals and laterals affect the use of water on the farm itself. This section will be divided into a discussion of canal and lateral systems.

Canal Lining and Management

The basic element in improving canal and ditch systems is the lining or piping of the channels so that seepage is alleviated. In the construction of these improvements, new turnout structures and water measurement devices are incorporated which improve the control and distribution of water, thereby providing a stimulus to irrigators for more efficient water utilization. The Bureau of Reclamation's 1975-1976 estimates of the costs to line the major canals in the Valley with concrete was slightly more than $40 million (USBR, 1976a). Referring to Tables 4 and 6 in the previous section, and assuming the linings would reduce seepage by approximately 80 percent, indicates that the average cost per ton of salt reduced is $200 to $360/metric ton.

When water is turned into the lateral system, it becomes the responsibility of the users entitled to the diversion. Single users served by an individual turnout are not uncommon, but most laterals serve several irrigators who decide among themselves how the lateral will be operated. Most of the multiple-use laterals, which may serve as many as 100 users, are allowed to run continuously with the unused water being diverted into the drainage channels. This practice would be almost completely eliminated if the only water diverted was that quantity appropriated to each acre in the company water rights. In addition, the employment of a demand system, based upon irrigation scheduling and limited by the water duty for the cropland, would be highly beneficial in improving crop yields while reducing subsurface irrigation return flows. The costs that would be passed on to the irrigator for a more regulated canal system would also provide added incentive for more efficient water management practices below the canal turnout. Thus, there would be an indirect economic incentive for better management.

Lateral Lining and Management

The benefits which would accrue from lining the lateral system in an area like the Grand Valley are essentially the same as described earlier concerning the canal linings. However, because of the vast extent and generally poor conditions of the lateral system, the effect of the laterals is much greater than the canals. As with the canal system, the appurtenances, such as the control and measurement structures, are an integral part of any lateral system improvements. Therefore, the additional benefits derived from more efficient water management cannot be ignored.

The extent of the lateral system is approximately 600 kilometers in length and, as shown previously, contributes more than 200,000 tons of salt to the Colorado River each year as a result of seepage. The costs of lining these channels with slip form concrete or buried plastic pipeline range from $10 million (Walker et al., 1977) to $30 million (USBR, 1976a). The unit salinity control costs, therefore, range from $50/ton to $150/ton.

There exists an obvious need for rehabilitation of the laterals, consisting of linings and regulating structures, before an effective salinity control program can be undertaken on the croplands. The reason is simply that there exists little means of water distribution on an equitable basis below the canal turnout. Aside from the canal turnout themselves, which could be rated individually, no observable or accurate means of measurement exists internally in most laterals. Without adequate control and measurement structures, it would be impossible to either regulate lateral diversions or equitably distribute the water among users.

ON-FARM WATER USE AND MANAGEMENT

The salinity entering receiving waters as a result of the inefficiency in the on-farm component of an irrigation system can be reduced but not completely eliminated. There must be at least some flow through the crop root zone in order to remove salts which tend to accumulate due to the concentrating effects of evapotranspiration. Unfortunately, few if any irrigation systems are operated in such a manner that the excess water application just equals the required leaching fraction. The excess leaching water generally dissolves additional salts from the soil and aquifer materials so that the total mass emission of salt from an irrigated area is greater than the total volume being diverted in the irrigation water. Consequently, the more inefficient an irrigation is, the greater the net salt pickup. The problem is compounded by the fact that irrigation systems do not apply water to the soil uniform by, which when combined with the nonhomogeneity of soil characteristics, results in an uneven distribution of the soil water in an irrigated field. Crop yield is directly related to supplying the plant with adequate moisture, and since the farmer wishes to maximize yield, the least watered areas are generally given sufficient water to meet the needs of the plant. The remainder of the field is overirrigated, but this does not cause substantial yield decreases even though nutrients are leached from the root zone. Experience has demonstrated that the irrigator knows when to irrigate, but not how much water to apply. As a result, most irrigators apply more water even to the least watered areas than required. And finally, water is frequently conveyed to various field locations via a lengthy system of earthen ditches that contribute substantial seepage losses to the underlying groundwater basin.

If the problems of on-farm water management are properly conceptualized, the remedies to a salinity problem evolve into one or various combinations of three alternatives:

1) On-farm conveyance networks can be lined or replaced to prevent seepage;

2) The uniformity of water application can be increased by altering irrigation practices or converting to more effective systems; and

3) The irrigator can be trained or advised regarding the amount of water required to refill the crop root zone and meet the minimal leaching requirement.

On-Farm Seepage Control

Many farmers have lined the perimeter of their farm conveyance networks to reduce seepage, maintenance, and labor. The most common lining methods include a concrete slip form lining, a buried plastic membrane, compacted earth, or converting the ditches to plastic or aluminum pipelines. Each of these alternatives are relatively inexpensive and have become accepted methods for improving on-farm water management. In the Grand Valley, the on-farm conveyance system can be lined for about \$7.50 per meter, which translates into a cost of about \$100 per metric ton of salt load reduction in the Colorado River. In order for the irrigator to operate his system effectively, flow measurement devices should be located so that the inflow to each field is known.

Improving Water Application Uniformity

In order to irrigate the least watered areas in a field without overirrigating other parts of the field, the uniformity of the application should be maximized. Since different irrigation systems have different uniformity problems, it is useful to segregate this discussion into: (a) surface irrigated systems; (b) sprinkler irrigated systems; and (c) trickle irrigation systems.

Surface Irrigation Systems--

The predominant form of surface irrigation in Grand Valley is furrow irrigation. The soils are relatively "tight" and combined with the 1 to 1.5 percent field slopes results in large volumes of field tailwater. The infiltration in these soils generally follows a decaying exponential function. Uniformity under furrow irrigation is maximized when the "intake opportunity time" at both ends of the field are equal. Since water is conveyed from the head end to the tail end of the field, equal intake opportunity times along the furrow are not possible. The least watered area of the field is at the bottom end, so under existing management practices, the highest attainable irrigation efficiency is achieved when the root zone in this area is just refilled.

There are two "operational" wastes which occur under furrow irrigation. The first, is the water percolating below the root zone described previously. The second, only alluded to, is the runoff from the lower end of the field. Efforts to reduce each one is competitive; i.e., measures to minimize runoff will increase deep percolation and vice versa. Since salinity is directly associated with deep percolation, local improvement programs will cause high runoff if not coupled with some system modification that will be described shortly. (In some irrigated areas, sediment erosion is a major problem and tailwater would be the highest priority for control.)

In the Grand Valley, furrow irrigation uniformity and consequently efficiency can be substantially improved by three alternatives. First, irrigation scheduling should always be based on sampling at the lower end of the field so that the minimal intake opportunity (or irrigation set) can be determined. Irrigation scheduling will be discussed later in this section. The flow in the furrow should be adjusted so that the time required for the flow to advance to the end of the field is about 25 percent of the minimal intake opportunity time. If these practices were implemented and strictly adhered to, local deep percolation volumes would be cut by more than 50 percent. The individual furrow length and discharge can be adjusted to satisfy these criteria. Unfortunately, such a program does not appear realistic in the Grand Valley.

The second method for improving furrow irrigation uniformities and efficiencies is called cut-back furrow irrigation. Under this method, the head ditch is sufficiently automated so that a large "wetting" furrow stream is introduced to quickly advance the flow down the furrow and then the flow is "cut-back" to a "soaking" flow rate to finish the irrigation. This technology has been well demonstrated in the Grand Valley with about the same unit salinity control costs as lining the on-farm conveyance channels. Cut-back irrigation has one notable advantage over simply controlling the existing system--the field tailwater is greatly reduced.

The final alternative for improving furrow irrigation uniformities in the Valley is to utilize large furrow streams (without causing erosion), collecting the excessive tailwater in a small reservoir, and then pumping this water back to the head of the field. This technology has been demonstrated on one field in the Grand Valley by the Colorado Water Conservation Board. Because of the low value of water in Grand Valley, there are some difficulties in gaining farmer acceptance for this tailwater reuse system. However, this technology represents the most efficient furrow irrigation system when operated in terms of a known soil moisture deficit and completely eliminates on-farm surface wastes. The unit costs of salinity control for reuse systems are higher than the cut-back option.

These three alternatives obviously imply that the slope of the field is fairly uniform. If not, land grading may be required. In the Grand Valley, with careful surface irrigation management, the salt loading can be substantially reduced by cultural practices such as planting row crops near the edge of a furrow (instead of midway between two furrows), so less time is required to "soak" the seed bed by lateral wetting (especially in the early irrigations).

Sprinkler Irrigation Systems--

A conversion from surface methods of irrigation to sprinkler irrigation systems by farmers in the Grand Valley would be highly beneficial in terms of efficient water use. Sprinkler irrigation systems, properly designed, installed and operated, have advantages both in terms of water quantity and quality. More uniform water application is generally possible on local types of soils, thereby minimizing deep percolation losses, and, of course, such a system should result in no tailwater runoff. The division of lands in the Valley are such that the most effective sprinkler system would be the familiar mobile "side-roll" or other portable systems. In the orchards, tow-line or solid-set sprinklers could be used. The unit salinity control costs should be approximately $200 per metric ton of salt load reduction for mobile systems and $300/ton for the solid-set systems.

Apart from the water quality benefits, there are many other advantages to farmers in converting to sprinklers. The labor savings are particularly noticeable in comparison with surface irrigation methods. With portable solid-set or permanent set systems, labor is negligible and the systems lend themselves to automation to other water application purposes (i.e., frost control, cooling, etc.).

Besides reducing nutrient losses as a result of reducing deep percolation, further fertilizer loss reduction can be achieved by the ability to use sprinkler systems to apply fertilizers at the time required by the plant. Water soluble fertilizers can be applied through the sprinklers with the timing and amount controlled to meet the needs of the plant. The ability to schedule fertilizer applications to plant needs (rather than to cultural operations as with surface irrigation methods) reduces the opportunity for leaching nutrients below the root zone. The amount of water applied can also be controlled to meet the needs of the crop, and thereby avoiding the excessively large deep percolation losses that commonly occur in the Grand Valley during the early season irrigations. Water soluble herbicides and insecticides can also be applied through the sprinklers.

Trickle Irrigation Systems--

Trickle or drip irrigation is a recently developed irrigation method and would appear to have potential for orchard crops in the Grand Valley area. This method of irrigation has gained attention during recent years because of the potential for increasing yields, while decreasing water requirements and labor input. The concept behind trickle irrigation is to provide the plant with the optimal soil moisture environment continuously. This is accomplished by conducting water directly to individual plants, through laterals running along each row, instead of providing water to the entire field as with flood or sprinkler irrigation. Another advantage is that trickle irrigation systems are easily automated. The multitude of lateral lines are supplied by manifold lines connected to the main line, which in turn, connects to the water source. A control head is provided, generally at the water source, to regulate pressure and flow and to filter suspended solids from the water. A fertilizer injection system is often incorporated into the control head.

A wetted profile, the shape of which is largely dependent on soil characteristics, develops in the plant's root zone beneath the "trickle" or "emitter." Ideally, the area between trees and between tree rows is dry and receives moisture only from incidental rainfall. Trickle irrigation saves water because only the plant's root zone is supplied with water and little water should be lost to deep percolation or soil evaporation under proper management. The only irrigation return flow is due to the leaching fraction that is necessary to prevent excessive salt buildup in the root zone. There is no surface runoff and very little nonbeneficial consumptive use of water by weeds. Water savings are effected through the ease with which the correct amount of water is accurately applied. Also, trickle requires very skilled technical assistance for nutrient balance and fertilizer applications (the grower needs outside technical assistance).

For irrigating widely spaced crops (i.e., trees), the cost of a correctly designed trickle irrigation system is relatively low in comparison to that for other solid-set or permanent irrigation systems. In orchards, the unit salinity control cost of a trickle irrigation system is comparable to that for a solid-set or permanent sprinkler system having the same level of automation. In addition, where clogging is not a problem and emitter line maintenance is minimal, operation and maintenance costs of the trickle irrigation system are usually quite low. However, in plantings of row crops or vines, where the average distance between emitter lines must be less than 3 meters (10 feet), the cost of trickle irrigation is relatively high. When a trickle irrigation is installed, there is usually a substantial need for technical assistance to insure that the plants are not being stressed and that a nutrient balance is being maintained.

Irrigation Scheduling

The results of the Grand Valley Salinity Control Demonstration Project indicate that irrigation scheduling programs have a limited effectiveness for controlling salinity in the Grand Valley under existing conditions. Excessive water supplies, the necessity for rehabilitating the irrigation system (particularly the laterals), and local resistance to change preclude managing the amounts of water applied during successive irrigations. To overcome these limitations, irrigation scheduling must be accompanied by flow measurement devices at all the major division points, farm inlets, and field tailwater exits. In addition, it is necessary for canal companies and irrigation districts to assume an expanded role in delivery of the water. Also, some problems have been encountered involving poor communication between the farmer and scheduler, as well as certain deficiencies in the scheduling program dealing with evapotranspiration and soil moisture predictions. These latter problems can be easily rectified, and correcting these conditions will make irrigation scheduling much more effective and acceptable locally.

The results of this demonstration project show that irrigation scheduling is a necessary, but not sufficient, tool for achieving improved irrigation efficiencies. The real strides in reducing the salt pickup resulting from overirrigation will come from the employment of scientific irrigation scheduling in conjunction with improved on-farm irrigation practices. In addition, improved agronomic practices should also be incorporated into an irrigation scheduling service (Jensen, 1975).

WATER REMOVAL

Drainage

Drainage investigations in the Grand Valley began shortly after the turn of this century when local orchards began failing due to saline high-water tables. Studies showed the soils to be not only saline but also having low permeabilities. At the time, the future development of the USBR's "Grand Valley Project" loomed as a severe threat to the low lying lands between it and the Colorado River. In answer to these drainage needs, the solutions were clearly set forth, but never fully implemented because of the large capital investment required. However, the citizens of Grand Valley did elect to form a drainage district supported by a mill tax levy in order to construct open ditch drains and some buried tile drains to correct trouble spots.

The construction of open drains has played an important role in Grand Valley. These drains serve as outlets for tile drainage systems, as well as intercepting and conveying tailwater runoff which would otherwise flow over surface lands, infiltrate, and contribute to additional subsurface groundwater flows, subsequently reaching the Colorado River with increased salt pickup.

Recent studies have shown that water intercepted by field relief drainage systems has salinity concentrations about 3000 mg/l less than if the subsurface flow continued to the river through the groundwater system (Skogerboe et al., 1974). A principal advantage of field drainage is that the effluent is a point source which can be disposed of or treated. Unfortunately, field relief drainage has unit salinity control costs more than an order of magnitude greater than any other alternative, and would, therefore, not be employed in any presently conceived salinity control program. An alternative and effective form of drainage--pump drainage--can be utilized in conjunction with desalination to reduce salinity at about the same cost as canal lining. This alternative is considered in more detail in the following discussion on desalting.

DESALTING

The development of desalination technology in the United States has been guided by the following basic objective as stated in the Saline Water Act of 1952 (PL 448):

> "to provide for the development of practicable low-cost means for producing from sea water or from other saline waters (brackish) and other mineralized or chemically charged waters, water of a quality suitable for agriculture, industrial, municipal, and other beneficial consumptive uses."

The objective of desalination as listed above has been given a massive research and development effort, although the application to large-scale systems is only now beginning to occur (USDI, USBR, 1973). The traditional scope of saline water conversion programs has been to reclaim otherwise unsuitable waters for specific needs. However, these programs have dealt almost exclusively with direct utilization of product water, rather than returning the project water to receiving waters in order to improve the overall resource quality. Thus, with mounting concerns for managing salinity on a regional or basinwide scale, the potential for applying desalination within the framework of an overall salinity control strategy is an interesting one. A desalting system as used herein consists of facilities for supplying raw water (water to be desalted) to the plant, the desalting plant itself, and facilities to convey and dispose of the brine (Figure 12). Transportation of product water beyond the confines of this system is not considered.

Desalting Costs

In general, the costs associated with desalting systems may be classified as either those expended during construction, or

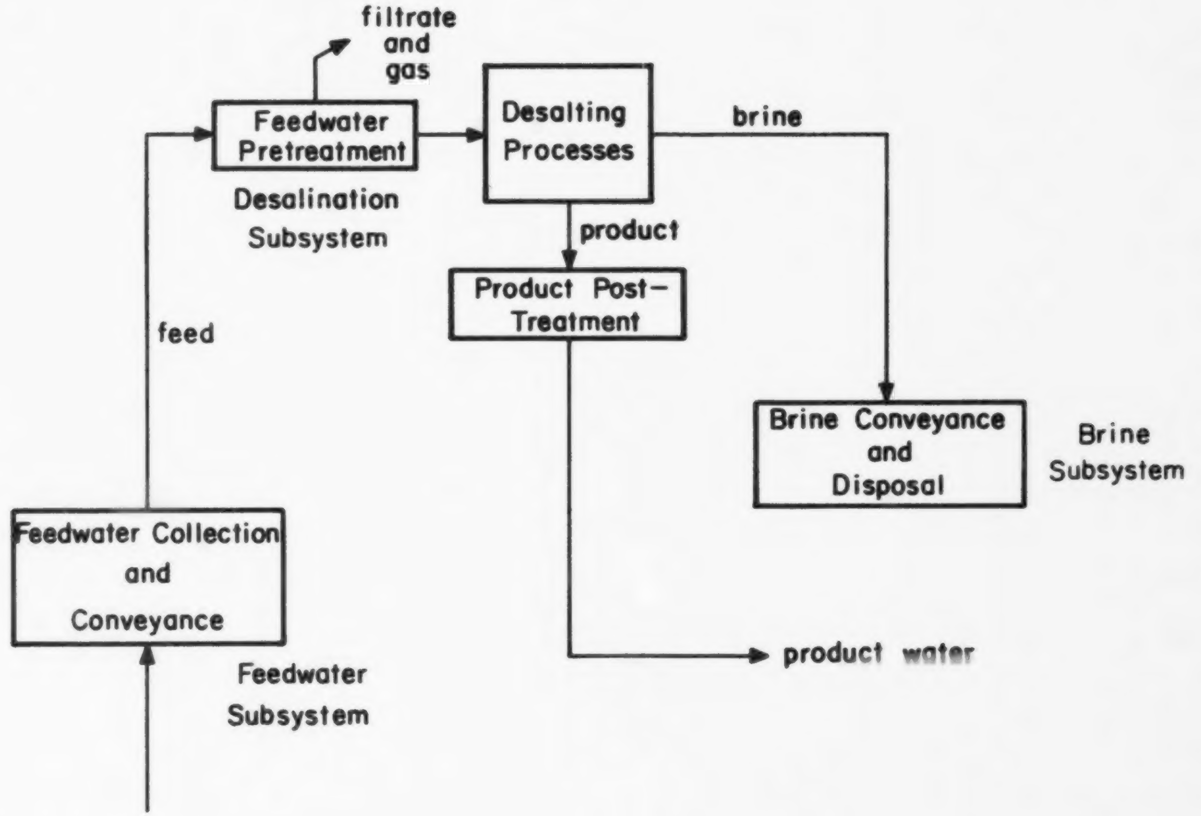

filtrate
and
gas
Feedwater
Pretreatment
Desalination
Subsystem
Desalting
Processes
brine
product
Product Post-
Treatment
feed
Brine Conveyance
and
Disposal
Brine
Subsystem
Feedwater Collection
and
Conveyance
product water
Feedwater
Subsystem

Figure 12. Schematic diagram of a typical desalination system.

those required annually to operate and maintain the facilities. These costs are subject to inflationary pressures and must, therefore, be periodically updated. Once costs are current, various relationships between the costs and system performance can be formulated. A detailed costing model is presented by Walker (1978).

Construction costs, capital costs, or investment costs include all expenses associated with building the appropriate facilities and can be subdivided into the following eight categories:

1) Construction costs, including designs and specifications, labor, and materials;

2) Steam generation equipment if utilized in the desalting process;

3) Site development expenses for offices, shops, laboratories, storage rooms, etc., and for the improvement of the surrounding landscape such as parking, grading, and fencing;

4) Interest during construction on funds borrowed to finance construction;

5) Start-up costs necessary to test the plant operation, train operating personnel, and establish operating criteria;

6) Owner's general expenses for indirect costs like project investigation, land acquisition, contract negotiation and administration, and other miscellaneous overhead costs;

7) Land costs for the site and conveyance facilities; and

8) Working capital to cover daily expenses involved in plant operation.

Annual operation and maintenance costs can be divided into six categories described as:

1) Labor and materials for plant or support facility operation;

2) Chemicals for pretreatment and process additions;

3) Fuel to power stream generation equipment;

4) Electricity for pumps, filters, etc.;

5) Steam generator operation and maintenance; and

6) Replacement of process elements.

After describing the individual costs associated with desalting systems, it is generally necessary to express such costs in either dollars per unit volume of product water (for water supply feasibility) or dollars per unit of salt extracted (for salinity control studies). These cost bases are determined by dividing the total annual costs by the annual volume of product water or brine salts.

Applications in the Grand Valley

The desalting processes that might be applied to the Grand Valley are as follows:

1) Multi-stage flash distillation (MSF);

2) Vertical tube evaporation - mutli-stage flash distillation (VTE-MSF);

3) Vapor compression - vertical tube evaporation -multi-stage flash distillation (VC-VTE-MSF);

4) Electrodialysis (ED);

5) Reverse osmosis (RO); and

6) Vacuum freezing - vapor compression (VF-VC).

Associated with each of these processes must be facilities to collect and convey feedwater and to convey and dispose of the brines. An evaluation by Walker (1978) for the Grand Valley indicated that local applications would most likely pump water from the cobble aquifer underlying the irrigated area, or divert the saline drainage and natural surface flows for the feedwater supply. Brines would be best injected into deep strata. Based on these criteria, Walker (1978) computed the scale distributed desalination costs for the Grand Valley conditions. These results are shown in Figure 13.

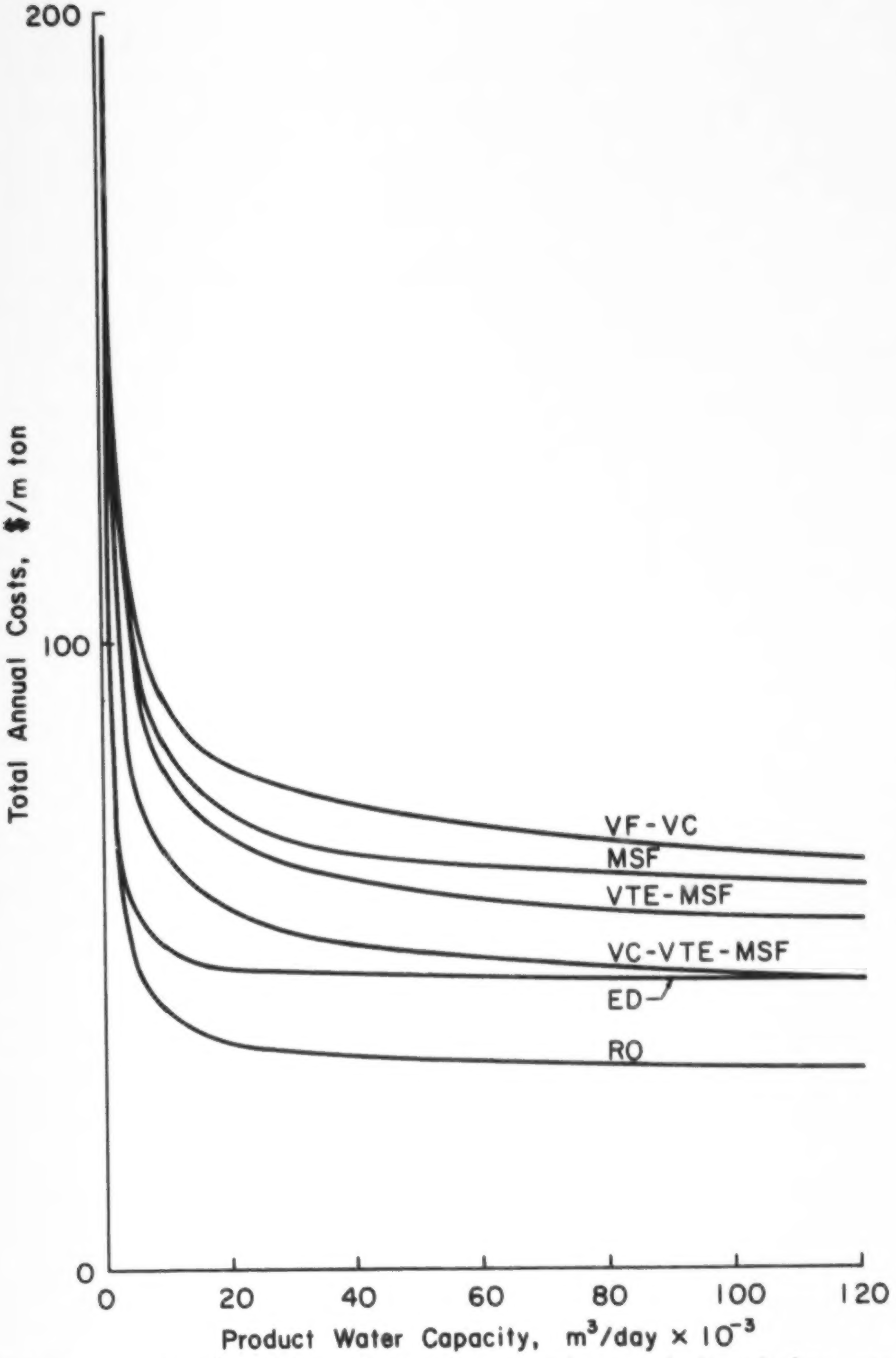


Figure 13. Relationship of plant capacity and desalting costs for various desalting systems that could be employed in Grand Valley.

SECTION 6

BEST MANAGEMENT PRACTICES

INTRODUCTION

Controlling salinity in a major river basin is a difficult task because of the mixture of diffuse and point sources of salinity. Generally, the best practicable solution lies in combining the strong features of several control measures and applying each to the conditions for which it is best suited. Salinity control technology in this regard remains to be developed since few investigations have managed to integrate the alternatives. If the control program is to be based on "best management practices," then this integration of alternatives should be "optimized" in accordance with a specific criteria for selecting one measure over another.

In an irrigated area, like the Grand Valley, traditional salinity control measures include canal and lateral linings along with improved irrigation practices including irrigation scheduling. Nevertheless, treatment of the agricultural system does not completely alleviate local salinity problems because only the salt pickup component of salinity can be reduced. By considering other measures such as land retirement, taxation, desalination, etc., a total salinity control program is possible by removing salts being transported through the irrigated system, thereby creating a "zero discharge" capability.

In the previous section, the array of alternatives for controlling salinity were outlined and evaluated. Some were obviously more applicable than others. Consequently, it is necessary to delineate those which can be utilized in the Grand Valley.

Taxation is strictly a linear application of estimated downstream damages and, therefore, does not adequately incorporate the costs of treating the problem by amending local irrigation practices. If the objective of the Grand Valley salinity control program is to reduce salt loading by less than 300,000 metric tons per year, the taxes would be higher than the costs to achieve the control. Plans calling for more than this level of control would find that the taxes undercharge the costs. In other words, there is a point where the costs of alleviating salinity are greater than the downstream damages. Taxation would, therefore, have to be based on a sliding scale representing the minimum cost strategy for reducing salinity. These kind of taxes, however, are simply repayment fees and are not generated from consideration of the entire economy. Consequently, taxation as developed earlier will not be included among the "best management practices."

Land retirement is a viable and competitive salinity control measure in some areas such as the extensive citrus groves near Yuma, Arizona (where land retirement is being implemented). These levels do not have as yet an alternative use which requires water. In the Grand Valley, there is substantial urbanization occurring and lands retired would sell for high prices to be developed as housing sites. Many areas in the Valley already converted to subdivisions utilize the water previously diverted for agriculture. Every local indication implies these water supplies are generally inadequate (i.e., the urban irrigator on less vegatative area requires more water to irrigate a smaller vegetative area because of lower water use efficiency). It does not appear that land retirement would be a long-term solution to the salinity problem.

All of the legal solutions and remaining economic solutions will be omitted from this section and considered independently in the following section when implementation is discussed. These solutions are difficult to employ alone because they directly or indirectly affect the kinds of physical improvements that will be evaluated here. Since field relief drainage is so costly, it will also be deleted from the array of alternatives. Thus, the alternative measures for controlling local salt loading can be reduced to lining or piping the canal and lateral conveyance system, modifying existing on-farm irrigation methods and practices, and pumping the saline groundwater or diverting surface drain flow into desalination treatment plants.

The best management practices for salinity control in the Grand Valley are delineated by integrating each of the alternatives in an optimizational context. The basis for this analysis is the "cost-effectiveness" relationship.

COST-EFFECTIVENESS ANALYSIS

Optimization Criterion

Optimization is generally a maximization or a minimization of concise numerical quantities reflecting the relative importance of the goals and purposes associated with alternative decisions. Of themselves, neither the goals nor purposes directly yield the precise quantitative statements required by systems analysis procedures. Therefore, the objectives require a mathematical description before alternative strategies can be evaluated (Hall and Dracup, 1970). The specific measure to facilitate this examination can be defined as the optimizing criterion. Probably the most commonly used and widely accepted "indicators" are found among the many economic objective functions. However, considerable controversy exists as to the most realistic of these tools. If, for example, aspects of a water quality problem could be priced in an idealized free market monetary exchange, the forces that operated would insure that every individual's marginal costs equalled his marginal gains, thereby insuring maximum economic efficiency. In the absence of this ideal situation, the optimizing criterion, in any case, is at best an indicator of the particular alternative.

Among the more adaptable economic indicators are maximization of net benefits, minimum costs, maintaining the economy, and economic development. The use of each depends on the ability to adequately define tangible and intangible direct or indirect costs and benefits. In water resource development, and water quality management specifically, the economic incentives for more effective resource utilization are negative in nature (Kneese, 1964). A large part of this problem stems from the fact that water pollution is a cost passed on by the polluter to the downstream user. Consequently, the inability of the existing economic systems to adequately value costs and benefits has resulted in the establishment of water quality standards, however inefficient these may be economically (Hall and Dracup, 1970). The immediate objective of water resource planners is thus to devise and analyze the alternatives for achieving these quality restrictions at minimum cost, the criteria chosen for this study.

The reader interested in the nature of the optimization technique utilized in the analysis of minimum cost is referred to Walker (1978).

Conceptual Minimum Cost Salinity Control Model

On a basinwide scale, a salinity problem is the combined effect of many irrigated areas, saline springs, diffuse natural inflows, and other miscellaneous sources. These salinity sources not only occur sequentially due to the geographic structure of hydrologic area, but are also often governed by differing administrative formulas. Consequently, the problem of determining an "optimal" strategy for a major river basin area rapidly becomes too large and too complex for direct analysis. One of the various mathematical techniques for optimizing complicated systems is to decompose the problem into a series of subproblems whose solutions are coordinated in a manner that produces the solution to the larger problem. One method applied to analysis of water quality improvements in the Utah Lake Drainage basin of central Utah provides both a simple and effective decomposition (Walker et al., 1973). The structure of the decomposition methodology referred to above is shown schematically in Figure 14. Individual levels of modeling are delineated to define water quality cost-effectiveness analyses at different stages of development enroute to a single representation at the ultimate basinwide scale.

The conceptual model illustrated in Figure 14 represents an additive approach for determining the minimal cost salinity control strategy in a river basin. A number of levels or subdivisions having similar characteristics can be defined to correspond to various levels of hydrologic or administrative boundaries in a region. Within each level, the alternative measures for salinity management are characterized by cost-effectiveness relationships. A more detailed review of the structure of cost-effectiveness functions and their interdependence will assist the reader in understanding the application of the conceptual model in later sections.

Description of Cost-Effectiveness Functions--

The alternatives for managing salinity on a basinwide scale fall into two categories: (a) those that reduce salinity concentrations by dilution or minimizing the loss of pure water from the system by evaporation; and (b) those that improve water quality by reducing the mass emission of salt.

Examples of the first category include weather modification to enhance stream flow, evaporation suppression, and phreatophyte control. Many of these approaches are more costly and difficult to apply than is justified by the salinity control achieved and are, therefore, not considered in this work. In the second category, such measures as saline flow collection and treatment, reduction in agricultural return flows, and land use regulation can be used to reduce the volume of salinity entering receiving waters. In this report, only saline flow collection and treatment and irrigation return flow management are evaluated. Under these assumptions, salinity control becomes a mutually exclusive problem that allows addition of individual solutions to derive larger solutions. By letting the spatial scale of the problem correspond to successive layering or additions, the multilevel approach is congruent to the subbasin breakdown of major hydrologic areas.

The smallest spatial scale considered in this analysis is that of a subbasin containing an irrigated valley or stream segment delineated by inflow-outflow data. In a major river basin, a number of river systems may combine to form the basin itself so there are actually a number of subdivisions in a river basin. Thus, vertical integration of subbasins yields the aggregate river basin. In this analysis the river basin, river subsystem, and subbasin divisions have been designated as levels 4, 3, and 2, respectively. Level 1 will also encompass the subbasin scale as will be described shortly.

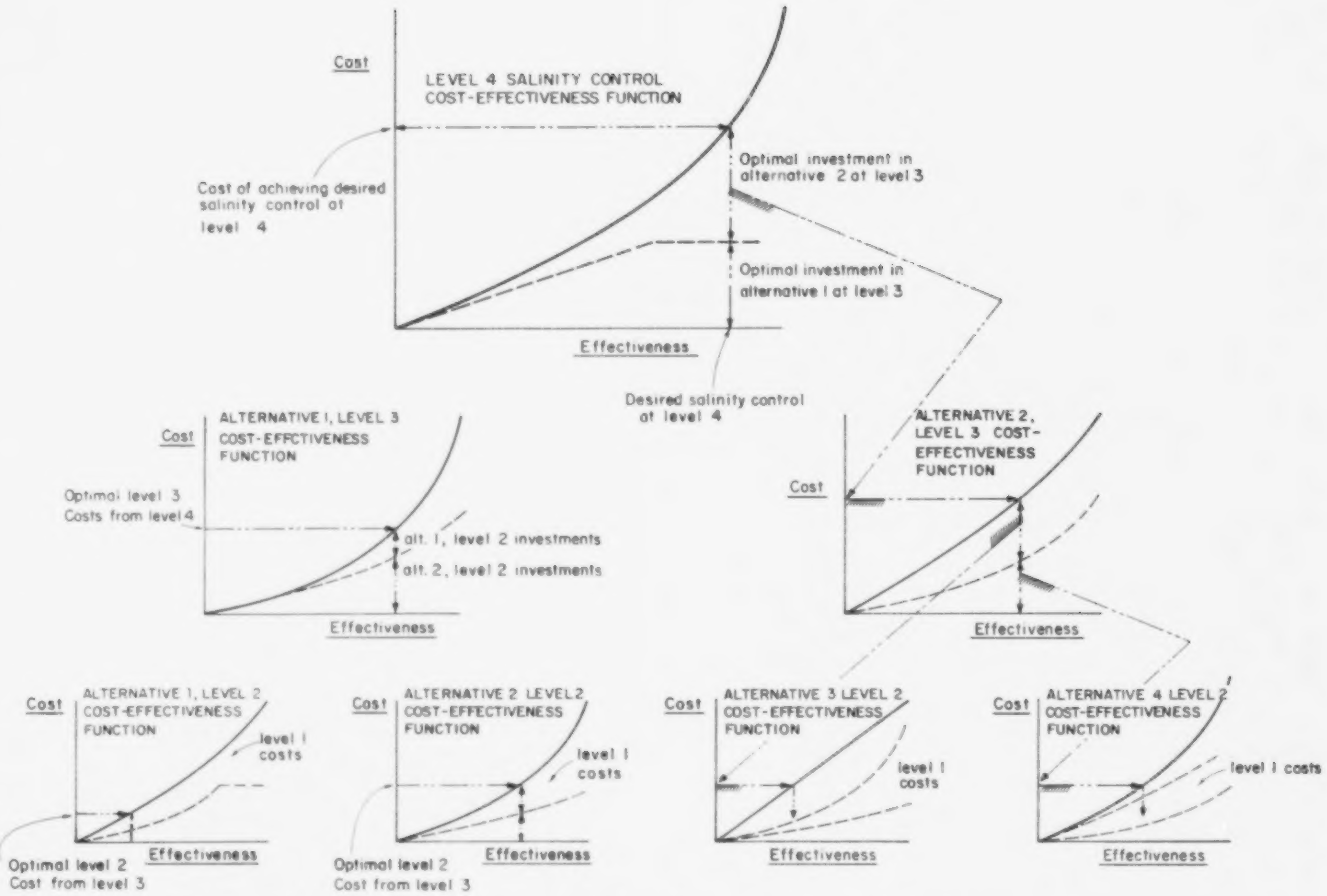

Cost
LEVEL 4 SALINITY CONTROL COST-EFFECTIVENESS FUNCTION
Cost of achieving desired salinity control at level 4
Optimal investment in alternative 2 at level 3
Optimal investment in alternative I at level 3
Effectiveness
Desired salinity control at level 4
Cost
ALTERNATIVE I, LEVEL 3 COST-EFFCTIVENESS FUNCTION
Optimal level 3 Costs from level 4
alt. 1, level 2 investments
alt. 2, level 2 investments
Effectiveness
ALTERNATIVE 2, LEVEL 3 COST-EFFECTIVENESS FUNCTION
Cost
Effectiveness
Cost
ALTERNATIVE 1, LEVEL 2 COST-EFFECTIVENESS FUNCTION
level I costs
Optimal level 2 Cost from level 3
Effectiveness
Cost
ALTERNATIVE 2 LEVEL 2 COST-EFFECTIVENESS FUNCTION
level I costs
Optimal level 2 Cost from level 3
Effectiveness
Cost
ALTERNATIVE 3 LEVEL 2 COST-EFFECTIVENESS FUNCTION
level I costs
Effectiveness
Cost
ALTERNATIVE 4 LEVEL 2 COST-EFFECTIVENESS FUNCTION
level I costs
Effectiveness

Figure 14. Conceptual decomposition model of a regional or basin salinity control strategy (Walker et al., 1977).

Associated with each level of the model are cost-effectiveness functions describing each alternative for controlling salinity. The structure of the cost-effectiveness functions includes two parts. The first is the function itself. In order to compare the respective feasibility among various salinity control measures at each level, the mathematical description of each alternative must be in the same format. Since this study involves evaluating the minimal cost strategy for reducing salt loading, each salinity control measure's feasibility for being included in the eventual strategy is based on the relationship between the costs of improvement and the resulting reduction in salt loading. The second part of the cost-effectiveness functions is what might be called a "policy space." To appreciate this aspect of the model, it is probably necessary to first discuss the determination of the optimal basinwide strategy.

Evaluating the Optimal Strategy--

Suppose the optimal policy for controlling salinity in a river basin had been determined with a minimum cost decision criterion. Such an analysis would provide two pieces of information. First, it would detail the cost associated with a range of reductions in salinity, and second it would delineate how much of these costs are to be expended in each river subsystem. In other words, the evaluation of the optimal strategy at level 4 involves systematic comparisons of level 3 cost-effectiveness functions and once the strategy had been determined, it also yields the optimal costs or expenditures in each level 3 alternative (river subsystem). In a similar vein, the level 2 costs and policies are determined from a knowledge of the level 3 optimal as determined during the level 4 analysis and so on. Thus, the cost-effectiveness function for any alternative within a level is:

1) The result of optimization of respective cost-effectiveness functions at a lower level and therefore a minimum cost relationship at every point; and

2) The sum of costs from optimal investments into each alternative at a lower level. The "policy space" is therefore a delineation of lower level cost-effectiveness functions.

The preceding paragraphs noted the detailing of a salinity control strategy once the optimal is known. Determining the basin optimal, on the other hand, begins at a level 1. A comparison of level 1 cost-effectiveness functions describing each alternative at that level produces the array of level 2 functions. Similar steps yield each succeeding level's optimal program. Thus, the multilevel approach described herein involves a vertical integration up through the levels to determine the optimal policy and a backwards trace to delineate its components.

MODEL APPLICATION IN THE GRAND VALLEY

The array of salinity control alternatives applicable as first level measures in the Grand Valley were described earlier in four primary classes: (a) on-farm structural and operational improvements; (b) lateral lining by slip form concrete or plastic pipeline; (c) concrete canal linings; and (d) collection and desalination of subsurface and surface drainage return flows.

On-Farm Improvements

On-farm water management improvements which improve irrigation efficiency and thereby reduce return flows include: (a) improved irrigation practices implemented through irrigation scheduling; (b) structural rehabilitation; and (c) conversion to more efficient methods of irrigation.

Irrigation Scheduling--

Recent studies in Grand Valley have indicated that irrigation scheduling services, even when accompanied by flow measurement structures, generally do not significantly improve farm and application efficiencies (Skogerboe et al., 1974a).

The overall impact of irrigation scheduling is estimated at only 10 percent of the total estimated on-farm potential improvement, which is insignificant by itself when considering the sensitivity of these types of costing estimates. Consequently, irrigation scheduling should be considered part of other irrigation improvement measures rather than considered a separate alternative salinity control measure.

Structural Rehabilitation--

Structural improvements in the system may include concrete lined head ditches or gated pipe to reduce on-farm seepage losses, land leveling for better water application uniformity, adjusting field lengths and water application rates to be more congruent with soil and cropping conditions, and automation to provide better control. Flow measurement and scheduling services should accompany these types of improvements in order to maximize their effectiveness.

In the Grand Valley, head ditch requirements are generally less than the capacity of the smallest standard ditch available through local contractors (12 inch bottom width, 1:1 side slope, slip form concrete). Assuming an average head ditch capacity of 0.05 m^3/sec, the estimated unit cost of head ditch linings is $7.50/m (Walker, 1978). This figure is well within the range encountered in the last two seasons in the Valley. There are approximately 1.3 million meters of head ditches in the Grand Valley contributing an estimated 95,000 metric tons of salt to the river annually. If linings were assumed to be 90 percent effective, the cost-effectiveness of head ditch improvements would be $113.40/ton (1.3 million meters x $7.50/m ÷ 86,000 tons).

Automatic cut-back furrow irrigation systems have demonstrated which, when combined with irrigation scheduling, may improve application efficiencies to 75 or 80 percent, thereby effecting an additional 60,000 ton decreases beyond the effects of the linings (Evans, 1977). In 1975, the installed cost of the cut-back systems was $11.50/m. Thus, the salt load reductions by lining head ditches (86,000 tons) and the additional 60,000 m ton reduction resulting from increased application efficiency results in a cost-effectiveness of $102.40/ton. Because of the small size of these ditches, linear distribution can be assumed without introducing significant error. In the case of the Grand Valley, it appears automation may be added to surface irrigation systems for the additional water use efficiency and consequent salt load reduction at about the same cost-effectiveness as the simple head ditch or gated-pipe improvements. Where head ditch capacities are large, concrete lining would generally be more cost-effective than piped systems. Automated cut-back furrow irrigation would further reduce salt loading due to improved irrigation efficiencies.

Field lengths may be modified along with land shaping to improve the uniformity of water applications. This would be particularly true in soils having a relatively high infiltration capacity, but not as effective in tight soils such as those encountered in the Grand Valley.

In order to completely control irrigation return flows, the method of applying irrigation water needs to be independent of soil properties. The application of sprinkler irrigation systems was shown by Walker (1978) to be approximately 80 percent efficient (application efficiency), whereas trickle irrigation systems could be expected to operate at the 90 percent level. Applying either system to the average field size in the Grand Valley (2-3 hectares) would be very expensive, so most systems would irrigate multiple fields. Mobile sprinkler systems would cost about $900 per hectare for coverages larger than 10 hectares. Trickle irrigation systems would cost approximately $1,800 per hectare for sizes greater than 2 hectares. Assuming irrigators would consolidate fields sufficiently to avoid the high unit costs encountered with small fields, the salt loading reduction for each system can be calculated as about 7 tons/hectare for sprinklers and about 9 tons/hectare for sprinklers and about 9 tons/hectare for trickle systems. These figures also take into account elimination of field head ditches and tailwater ditches. Mobile or portable sprinkler systems would have average salinity cost-effectiveness ratios of approximately \$132/ton, while the respective range for trickle systems would be about \$200/ton. Solid-set sprinklers would be at least double these figures and are therefore not evaluated. Center-pivot systems would be difficult to apply in the Grand Valley because of the small average size of land holdings.

Optimal On-Farm Improvement Strategies--

The first level cost-effectiveness function for on-farm salinity control is developed by computing the minimum cost strategy at various levels of on-farm control. These results for the Grand Valley case are shown in Figure 15.

The actual computed cost-effectiveness relationship for on-farm improvements is the step function shown as the solid lines. This characteristic occurs because of the linear assumption regarding the distribution of costs and salinity impacts. The smooth curved line represents a best fit through the cost-effectiveness distributions.

Two major strategies evolved in the analysis of on-farm improvements: (a) improvements to the existing system creating salinity reductions up to about 150,000 tons annually; and (2) system conversions to provide controls up to approximately 220,000 tons annually. Irrigation scheduling should be incorporated with all alternatives. Of particular interest here is the fact that the alternatives are mutually exclusive. In other words, in implementing an on-farm salinity management plan, either one or another is optimally chosen. For instance, if planners selected on-farm improvements to reduce salinity by more than 150,000 tons, the alternatives would be limited to changing to sprinkler or drip irrigation methods. Below the 150,000 ton figure, head ditch lining and/or automation would be optimal. This structure of the cost-effectiveness is unique among the alternatives as the reader will note in succeeding sections. This uniqueness is based on the fact that on-farm improvements themselves are mutually exclusive and limited in their expected effectiveness.

Lateral Lining and Piping

Laterals have been defined as the small capacity conveyance channels transmitting irrigation water from the supply canals and ditches to the individual fields. Most of these laterals operate in a north-south direction and can carry the flows in relatively small cross-sections. Although the capacities of the laterals may vary between 0.06 and 1.4 m^3/sec, most capacities would be within the range of 0.06 to 0.20 m^3/sec. Utilizing a median value of 0.20 m^3/sec yields a concrete lining cost of approximately \$16/m. Alternative use of PVC pipe approximates

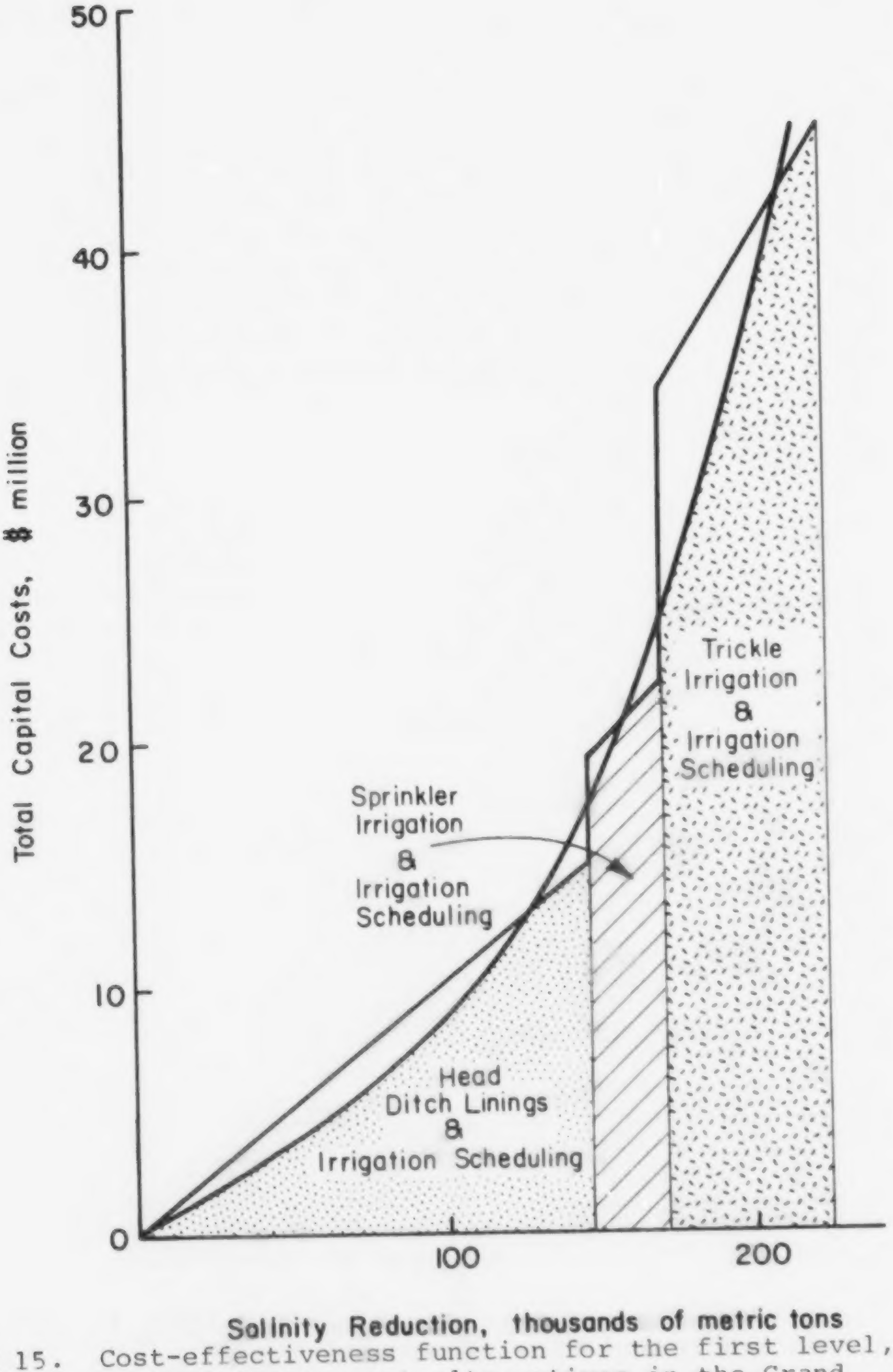


Figure 15. Cost-effectiveness function for the first level, on-farm improvement alternatives in the Grand Valley.

concrete lining costs for this capacity and a further distinction will not be made.

As noted earlier, Grand Valley laterals extend approximately 600,000 meters, less than one-half the length of field head ditches. Seepage under existing conditions contributes about 202,000 metric tons, or slightly less than the on-farm contribution. Although no attempt is made to distribute the lateral lining costs to account for variable capacity, the cost-effectiveness function for Grand Valley lateral lining is about $50 per metric ton. Thus, the estimated costs of lining the total lateral system in the Valley is about $10 million. It should be noted that in personal contact with the USBR, (1976a), costs for the lateral linings were estimated to be more than $30 million in 1976.

Canal and Ditch Lining

There are 14 major canal and ditch systems in the Grand Valley ranging in length from 74 kilometers for the Government Highline Canal (17 m^3/sec capacity) to 4 kilometers for the Mesa County Ditch (1 m^3/sec capacity). The pertinent parameters for each canal, along with the seepage contribution to salt loading, were given earlier. The results of an optimal canal lining program are given in Figure 16, which shows the total capital construction costs as a function of the annual salt load reduction to be realized (Walker, 1978).

The results obtained in optimizing canal lining policies are interesting in the sense that they demonstrate the need to initiate linings on more than one segment of the conveyance system when full-scale implementation begins. This may not be practical from a planning or scheduling standpoint.

Desalination

Desalting evaluations involved first determining the most cost-effective process and, second, the most cost-effective feedwater and brine disposal facilities. The optimal desalting policy in the Valley utilizes a reverse osmosis system with feedwater wells and brine injection wells (Walker, 1978). To express desalting cost-effectiveness in the same format as the agricultural alternatives, the costs are plotted against the mass of salts removed from the system. For the purposes of this report, an interest rate of 7 percent and a usable life of 30 years will be assumed. For the reverse osmosis system, Figure 17 shows the resulting cost-effectiveness function.

Whereas agricultural salinity control costs exhibit increasing marginal costs with scale, the opposite is true for desalting systems. In an optimizational analysis, therefore, the respective feasibility of desalting technology is maximized for large-scale applications. For small systems, desalting is

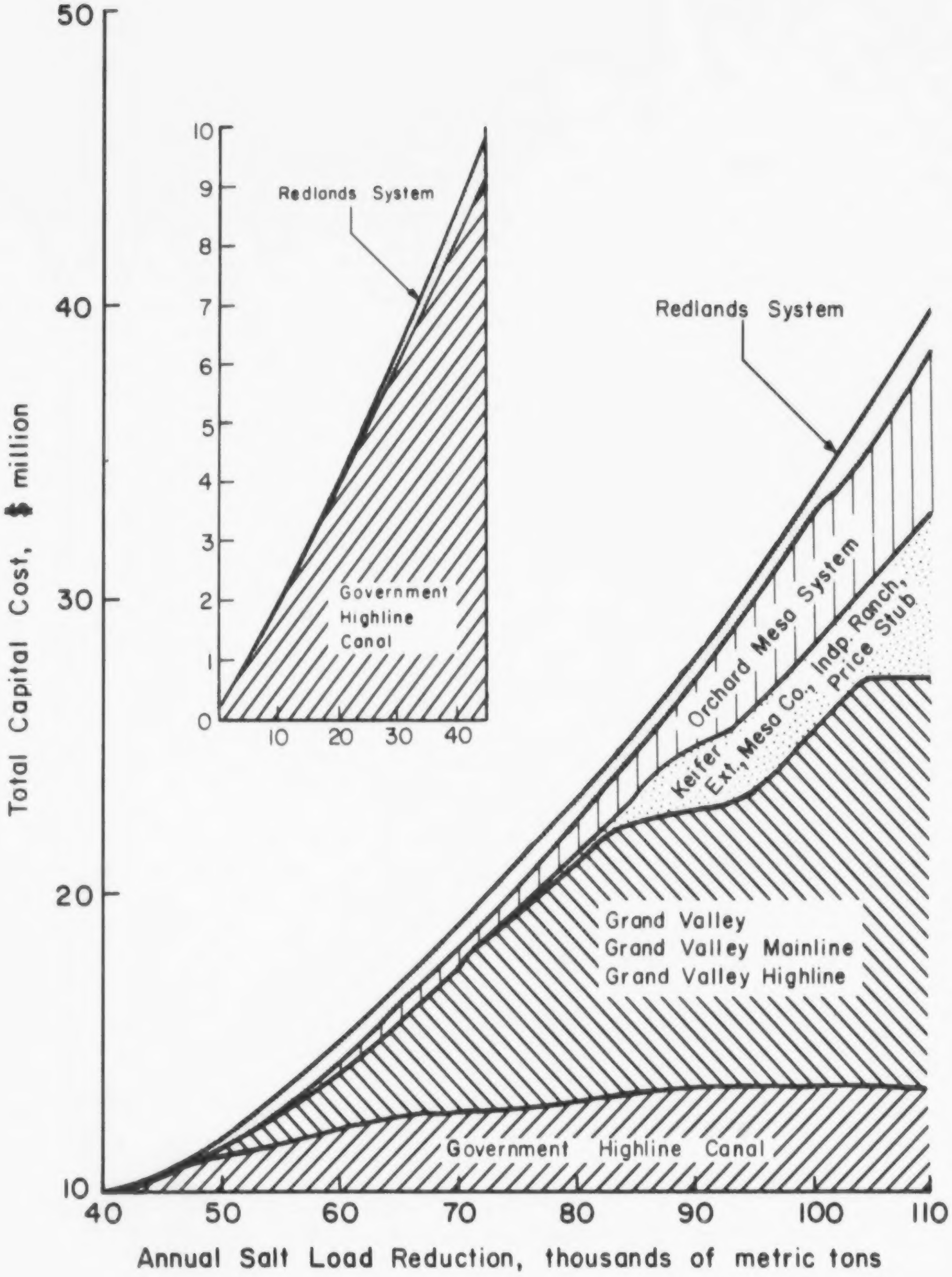


Figure 16. Optimal Grand Valley canal lining cost-effectiveness function (Walker et al., 1977).

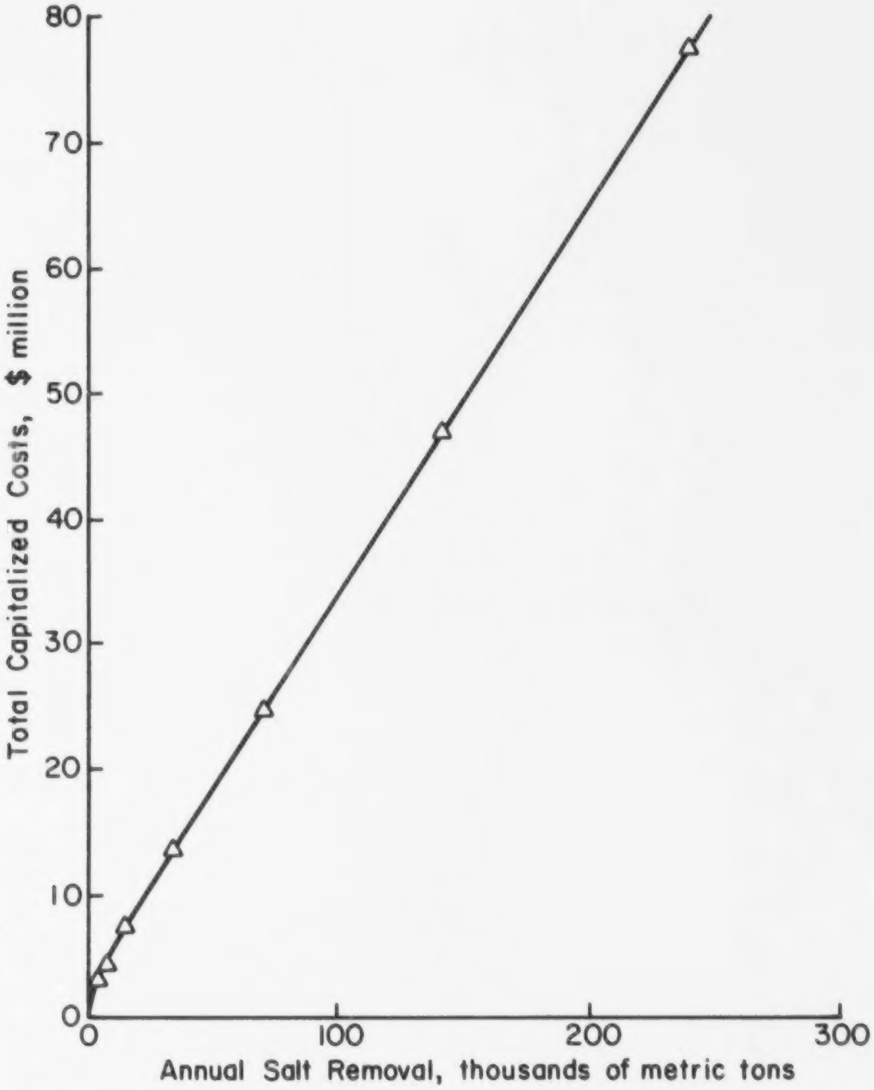


Figure 17. Grand Valley desalination cost-effectiveness function (Walker et al., 1978).

much less cost-effective than treatment of the agricultural system. As these factors are considered, a linear approximation representing the average marginal cost would serve at least as well as the nonlinear function. Consequently, desalting cost-effectiveness in the Grand Valley can be represented by using a present value cost of $320 per metric ton of salt reduction (Walker, 1978).

BEST MANAGEMENT PRACTICES

The individual cost-effectiveness functions at the first level (desalting, canal lining, lateral lining, and on-farm improvements) are optimally integrated to determine the minimum cost salinity control strategy for the Grand Valley. These results are shown in Figure 18.

Consider three points on the Grand Valley cost-effectiveness curve (Figure 18): (a) total costs = $15 million, salt loading reduction = 266,000 tons; (b) total costs = $40 million, salt loading reduction = 403,000 tons; and (c) total costs = $80 million, salt loading reduction = 530,000 tons. For convenience, these three points have been designated as Cases 1, 2, and 3, respectively.

If the expenditure in the Grand Valley is to be $15 million in 1976 value dollars (Case 1), the optimal strategy in so doing is found from a vertical trace at this point on the curve representing the Valley (Figure 18). Specifically, $10 million should be invested in lateral linings and $5 million in on-farm improvements. Referring back to the paragraphs on lateral lining, it is noted that a $10 million investment covers the cost of lining the entire system. Thus, for Case 1, the first part of the strategy is to line the lateral system entirely. In a similar backward look to Figure 15 representing the level 1 relationship for on-farm improvements, it is seen that a $5 million cost corresponds to about 64,000 ton reduction in the on-farm salinity contribution, and is so accomplished by head ditch linings, or cut-back irrigation, and irrigation scheduling.

A $40 million salinity control investment (Case 2) in the Grand Valley is seen from Figure 18 to reduce salinity by 403,000 metric tons by spending $10 million lining the lateral system, $20 million making on-farm improvements and $10 million for lining some of the major canals. Referring again to Figure 15, a $20 million investment in on-farm improvements implies reducing the on-farm salt contribution by 156,000 tons by irrigating nearly all of the irrigated land with portable or mobile sprinkler systems. Figure 16 showed that $10 million in canal lining would accomplish a 45,000 ton reduction in salt loading. To do this, a small (essentially insignificant) amount

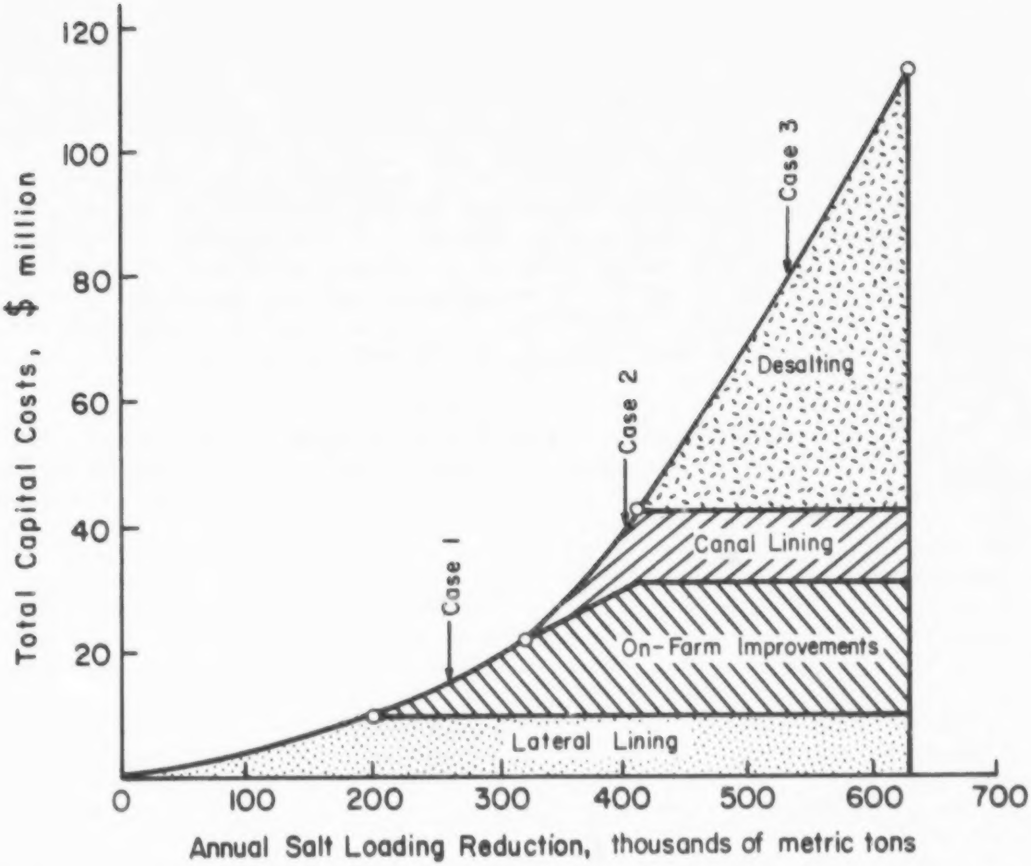


Figure 18. Grand Valley second level salinity control cost-effectiveness function.

of lining should occur in the Redlands system with the remainder being applied to the Government Highline Canal.

Case 3 shows that agricultural improvements should stop at $42.6 million, with any remaining salt volumes to be removed from the system through desalination of the subsurface irrigation return flows. The $42.6 million figure for local agriculture includes $10 for lateral lining, $21 million for on-farm improvements, and $11.6 million in canal lining. On-farm improvements would still involve conversion to sprinkler irrigation in conjunction with irrigation scheduling.

The mathematics of this analysis indicates the minimum cost salinity control strategy for the Grand Valley, but a planner or administrator must also consider the practicality of the solutions. For example, in the third case, it would probably be unrealistic to line a very small portion of the Redlands Canal system; consequently, a decision would likely be made to invest all of the funds into lining the required length of the Government Highline Canal. Likewise, on-farm improvements may be limited to converting the existing system to a sprinkler irrigated system with some measure of control to increase application efficiencies beyond those assumed for this analysis. The point to be made is that at this level of investigation, the inherent assumptions allow a certain amount of flexibility to account for some of the intangible social-institutional factors involved in an implementation effort.

In representing what might be called the best management practices for the Grand Valley, it must be realized that the four major implementation alternatives (lateral lining, on-farm improvements, canal linings, and desalting) only represent "structural measures." Consequently, nonstructural alternatives such as land retirement, influent and effluent standards, taxation, and miscellaneous enforcement options are not included. Nevertheless, the value of this sort of analysis can be clearly demonstrated. In the Grand Valley, a plan might be proposed in which all of the canals would be lined, all of the laterals lined, and some on-farm improvements to reduce salt loading by 450,000 metric tons annually. Looking at Figure 15 and 16, and the comments describing lateral linings, shows a total cost of such a program of $65.5 million. Figure 18 indicates the same reduction could be accomplished with a $54 million investment if the on-farm role were expanded, the canal lining program diminished and a limited desalting capacity were included. Thus, this optimization analysis illustrates how a $11.5 million savings (21 percent) can be achieved.

The eventual program in the Grand Valley is dictated by its respective feasibility in comparison to similar cost-effectiveness studies on the other subbasins in the Upper Colorado River Basin. In fact, the level of investment in the entire river system for salinity control depends on the level of damages created by the salinity. Since the completed four level analysis is not available, it is interesting to compare downstream damage with costs in the Grand Valley. Note that the estimates of marginal cost and downstream detriments must be the same. Walker (1975) reviewed much of the literature descriptive of the California, Arizona, and Republic of Mexico damages. At the time, Valentine (1974) had proposed damages of \$175,000 per mg/ℓ of increase at Imperial Dam (\$146 per ton in Grand Valley assuming 8 percent interest). Other estimates in terms of equivalent damages attributable to Grand Valley range upward. A representative figure is \$190/ton as proposed by the USBR (Leathers and Young, 1976). Some as yet unpublished figures now place these damage figures as high as \$375/ton. If the minimum cost curve in Figure 18 is differentiated to approximate marginal costs and be congruent with these damage figures, the \$146 per ton damage estimate of Valentine (1974) falls at a 300,000 ton reduction, while the \$190 per ton and \$375/ ton figures occur at 355,000 tons and 538,000 tons, respectively. Figure 19 is a plot of the marginal Grand Valley salinity costs as a function of salt loading reduction. Thus, not considering secondary benefits in the Valley, or obviously all the consequences in the lower basin, the level of investment in the Grand Valley could range between \$19 million for \$83 million. In any event, it can be seen that the actual policy for salinity control in a subbasin depends on decisions made at higher levels. Similarly, within a subbasin the measures implemented to control salinity change as the emphasis on the subbasin itself changes.

Sensitivity of Results

In earlier sections of this report, two major discrepancies with other investigative or planning groups were noted. The first was the difference between the salt contributed by canal seepage and that contributed by on-farm sources. The second difference was that the authors' lateral lining cost estimate was about one-third of the estimate made by the USBR (Walker et al., 1977). In order to evaluate these differences on the Valley's best management practices, the optimizational analysis was adjusted to account for the first differences and then the combined effect of both differences. The results are shown in Figures 20 and 21.

In the first case, optimal on-farm investments have been reduced by more than 13 percent while the expenditures in canal lining have more than doubled. The second case indicates that the higher priced lateral lining emerges in about the center of the on-farm and canal lining policies. In addition, the costs of the program are substantially increased for all levels of possible salt loading reductions. The best management practices for salinity control in the Grand Valley follow about the

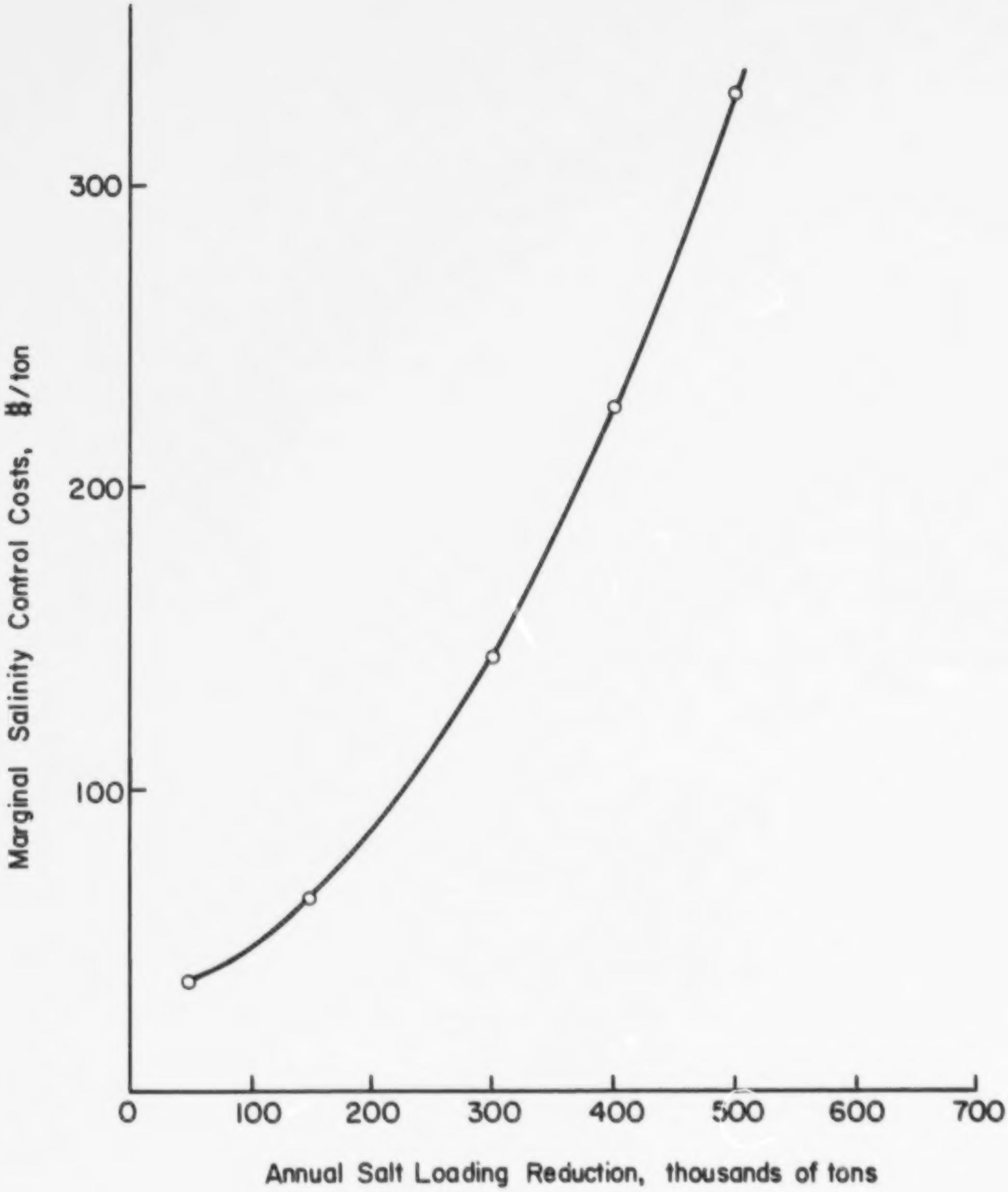


Figure 19. Marginal cost function of optimal salinity control strategy in the Grand Valley.

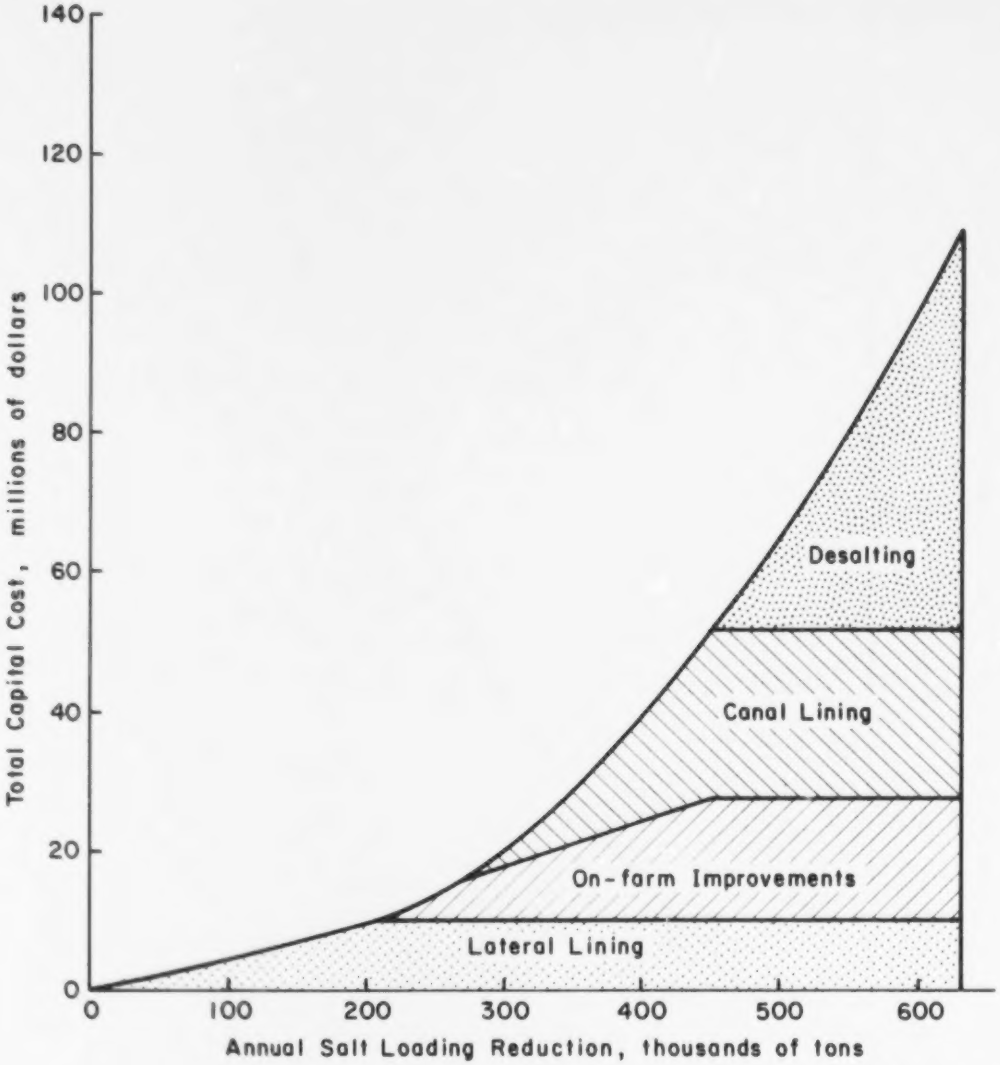


Figure 20. Grand Valley best management practices based on the hydro-salinity system proposed by Kruse (1977).

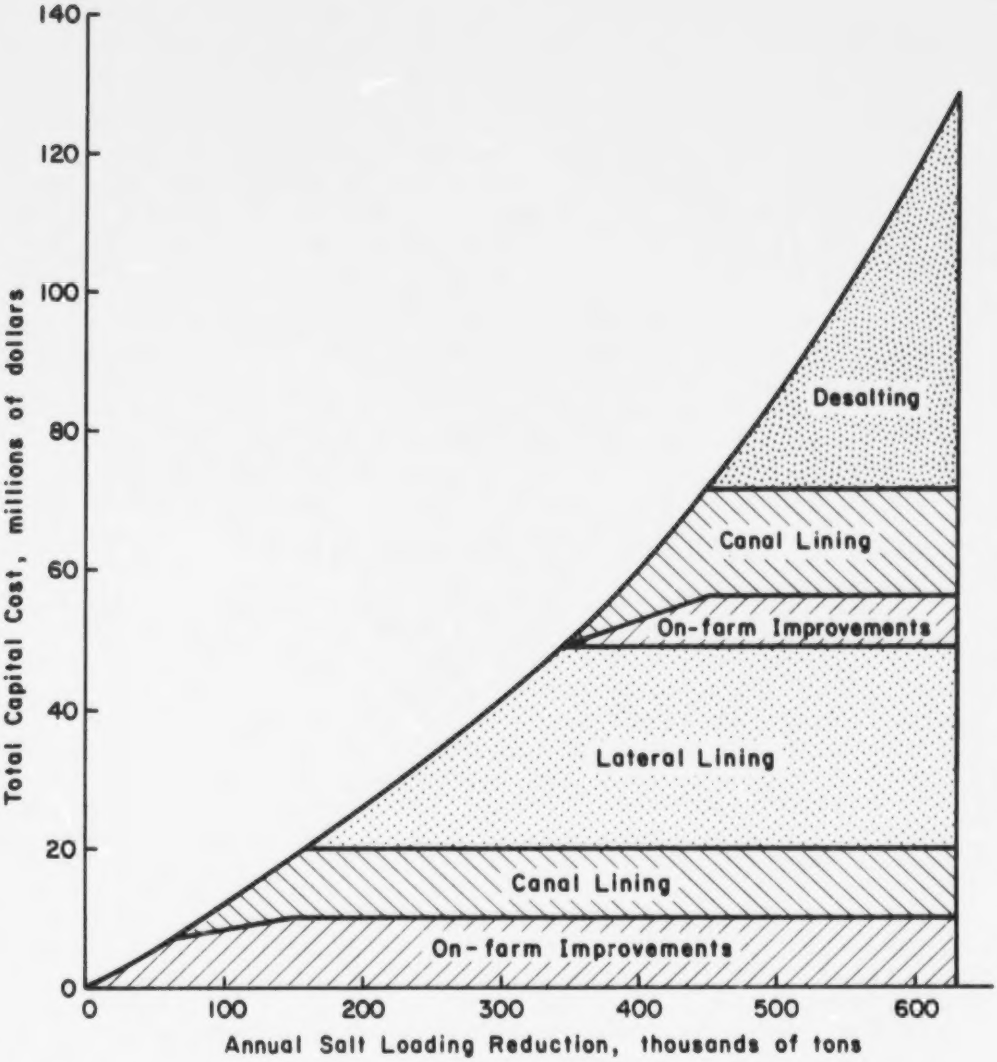


Figure 21. Best Management practices for the Grand Valley assuming the hydro-salinity budget for Kruse (1977) and a threefold increase in lateral lining costs.

same course of events irrespective of the hydro-salinity numbers utilized. If the lateral lining costs, however, are increased by utilizing more expensive pipe, the overall effect will be significant.

It should be noted in closing this part of Section 6, that the USBR has updated the estimated canal lining and lateral lining costs (USBR, 1977). Figures presented in this report are based on early 1976 estimates and can be updated if desired. However, even correcting for the effects of inflation does not reconcile the difference, because the writers have used different construction materials to control salinity than has the USBR in their estimates. For example, there is no reason to utilize concrete or high-head PVC pipelines in the Grand Valley lateral lining programs (as now planned) when properly installed low-head PVC or slip form concrete will perform as well. The properly installed low-head PVC or slip form best management practices are, of course, affected by decisions to use more expensive lining materials where unnecessary. In fact, use of concrete pipe for laterals causes this salinity control alternative to be substantially less cost-effective than most potential on-farm improvements.

IMPACT IN THE COLORADO RIVER BASIN

In Section 4, the hydro-salinity system of the Grand Valley was described in terms of the 1968 water year which is thought to be representative of the average condition. More exhaustive review of the USGS water sampling data shows some disparity with the figures utilized herein, but the differences are unimportant for the points to be discussed in the following paragraphs. The writers estimate that the prevention or removal of one metric ton of salt from the Colorado River will improve the water quality leaving the State by 2.17×10^{-4} mg/ℓ. Thus, a 400,000 metric ton salinity program in the Grand Valley could be expected to improve the quality of flows leaving the State in the Colorado River by approximately 87 mg/ℓ. The Bureau of Reclamation computes a 1976 modified condition at Imperial Dam in which a one metric ton reduction in salt loading will reduce salinity concentrations by 1.16×10^{-4} mg/ℓ (USBR, 1977). Again, a 400,000 ton reduction in the Grand Valley would improve water quality at Imperial Dam by more than 46 mg/ℓ.

At the time of this writing, existing plans call for a salinity control program of about 400,000 metric tons annually in the Grand Valley. Long-term monitoring of the river outflows will establish the exact magnitude of the salinity reduction. However, the vital issue is the maintenance of the 1972 salinity levels at Imperial Dam (800 mg/ℓ), a policy which has been generally accepted as the long-range goal. The USBR estimates that development of the remaining Colorado River entitlements would increase salinity concentrations at Imperial Dam by 300 to 400 mg/ℓ. Consequently, the Grand Valley salinity control program can be expected to eliminate about 10 percent of the problem which will require attention by the year 2000. In fact, if all of the problem is to be amended such that the 1972 water quality goal is protected, combined reduction in salt loading and evaporative concentration must equal an equivalent 3 million ton salinity control effort. Thus, many irrigated areas must be included in the eventual program as well as the improvement of other factors contributing to salinity in the Basin.

SECTION 7

ECONOMIC AND LEGAL OPTIONS

The development of best management practices in the previous section provides for the most cost-effective salinity control program in Grand Valley utilizing technologies that are not only appropriate, but they have also been demonstrated on farmers' fields to evaluate their acceptability to farmers. The implementation of these cost-effective and acceptable technologies requires some consideration of the economic and legal options. A combination of physical improvements and institutional rearrangements are most likely to provide the most implementable salinity control program. The three options to be discussed below are land retirement, taxation, and development of a water market. Other considerations involved in implementation will be discussed in Section 8.

LAND RETIREMENT

Much of the research effort by physical scientists concerned with controlling rising levels of salinity in the Colorado River Basin has focused on structural technologies. These means typically require extensive technical and material input often leading to substantial public and private investments. Land retirement is one nonstructural control option that deserved careful study since acreage reduction or desalination are the only technically feasible methods which can be employed to achieve the zero discharge objective proposed in the 1972 federal water quality legislation (Public Law 92-500).

To determine whether land retirement can be feasible on economic efficiency grounds, two sources of information are required: (a) the direct and indirect costs of removing land from irrigation; and (b) the benefits or incremental reduction in damages that would occur as a consequence. Direct costs should accurately reflect the incomes foregone from farming of the retired irrigated lands. Included in the indirect costs should be the net effects of costs and benefits issuing from resource reallocation, social transition, impacts on environmental amenities, and other consequences in the affected region.

An interindustry (input-output) model serves as the underlying structure for the analysis reported by Leathers and

Young (1976). The input-output model is an analytical accounting technique commonly used in the evaluation of "total" economic impacts of exogenous (or outside-induced) changes in an economy. Because of the interdependence among industries in a well developed economy (which may include small or large regions), secondary (or indirect) impacts are often thought to be just as important as the primary (or direct) impacts of an induced change. For this reason, the basic approach adopted in the study by Leathers and Young (1976) is an indirect impact analysis.

Land retirement mechanisms might include one or more of a number of options and can be either voluntary or involuntary depending on the level of public acceptance and participation in the program. The objective is to discontinue irrigation of selected acreages, thus eliminating all future salt loading from these sources. Specific program options evaluated by Leathers and Young (1976) involve a permanent withdrawal of water supplies.

Withholding irrigation water from previously cultivated acreage in the Grand Valley might be accomplished on a voluntary basis by State purchase of existing water rights from willing sellers. Because of the Grand Valley's arid climate, this would mean that farmland is taken out of production altogether, eventually returning to desert. State purchase of privately-held water rights through legal condemnation proceedings would constitute a compulsory mechanism. Both would, in effect, amount to land purchase since desert grazing land is of nominal value by comparison.

If a voluntary land retirement program is to be viable, this implies that some farmers in the Valley would be willing, to sell their farms (or a portion of their acreage) at a price that exceeds the present value of their long-run, capitalized earnings. In the case of "marginal" farms, this would mean that some individuals would be willing to trade the present value of farming (in the long run) as a "consumption activity" for an alternative activity made available by the purchase offer. (If the land were subdivided into suburban homes, then there would be a high likelihood that lawn irrigation would contribute substantially to the salt load reaching the Colorado River). Under an involuntary program, it would probably be necessary that the offer price exceed the present market value of representative irrigated acreages. The program would have an added flexibility if willing sellers under a voluntary retirement scheme could select the marginal acreages on their farms (perhaps difficult areas to irrigate where water losses are high and productivity low) for purchase by the State--analogous to the soil bank program (Public Law 89-321). Under such an option, the costs of the program might be reduced appreciably.

Two different options were examined by Leathers and Young (1976). Option I represents a partial retirement scheme. Specific areas of irrigated land which are markedly less productive (since they tend to have high salt content and/or serious natural drainage problems that hinder plant growth) are selected for retirement. Leathers and Young (1976) have stated that approximately 3,500 hectares in the Grand Valley fall into this category. Together they represent 14 percent of the area's irrigated lands and 8 percent of the areas' crop output. Since these areas of relatively unproductive soils are not contiguous in large blocks, retirement of such lands would control deep percolation from fields and seepage from farm head ditches, but would not reduce seepage losses in the main conveyance system.

A different strategy (Option II) considers the effect of retiring an entire irrigation district. All canals and laterals controlled as an integrated unit and the acreage (both poor and productive) they service would be withdrawn from production. With this option, land retirement implies the inclusion of canal and lateral seepage losses, which would not be the case under the first option. Accordingly, the costs of retirement are compiled by Leathers and Young (1976) on the basis of two assumed rates of annual salt reduction per acre: 4.9 metric tons under Option I, and 7.4 tons under Option II. The Government Highline Canal was chosen to illustrate the impacts of Option II, which is assumed representative of the Valley as a whole in terms of both productivity and salt pickup, so that results could be generalized to a full land retirement program (Leathers and Young, 1976).

A summary of results presented by Leathers and Young (1976) for the two options is shown in Table 10. In order to present these data in the same units as used throughout this report, the figures are expressed as the dollars per metric ton reduction recovered to the present time of early 1976. The interest rate is assumed to be 8 percent and the period 30 years.

In general, the incremental costs of salt removal (in $ per metric ton), using the provisional estimates of salt pickup, appear to be competitive with other more expensive controls such as canal lining, drainage, and desalting. However, the cost-effectiveness of the program is quite sensitive to assumptions regarding estimates of the quantity salts removed and the value of the salts removed. Accordingly, it is important that these assumptions be considered very carefully in comparing alternative salinity control programs. For example, the cost of partial retirement (Option I lands) varies from $76.50 per ton to $177.80 per ton depending on the assumed rate of salt pickup per acre, and more than double if the regional economic impact is viewed. Leathers and Young (1976) believe that the regional accounting stance provides a fairly generous upper bound on total program costs.

TABLE 10. COST-EFFECTIVENESS OF SELECTED LAND RETIREMENT OPTIONS (LEATHERS AND YOUNG, 1976)

Salts Removed (m ton/ha)	Dollars per m ton	
	Lower Bound	Upper Bound
Partial Land Retirement (Option I)		
2.7	177.80	500.70
4.9	99.00	277.90
6.4	76.50	214.90
Complete Land Retirement (Option II)		
4.5	245.30	586.20
7.4	149.60	356.70
10.0	111.39	266.70

TAXATION

Experience has proven that uncontrolled use of many natural resources cannot be maintained, particularly the assimilative capacity of air and water. These resources have often been overloaded with a vast array of pollutants threatening the health of both human and biotic environments.

Much of today's problem can be understood by examining the historical perspective with which natural resources were developed and utilized. Initially, the supply exceeds the demands, and it is economically "free," but, with development, such resources became "scarce" in the sense that competitive pressure is put on the limited supply provided by nature. At the point where the scarcity develops, neither the private market nor the public structures for regulation are capable of equitable allocation. Negative externalities begin to mount, and the various environmental systems may be severely damaged. As a result, this country has incorporated public regulation in the form of quality standards to manage pollution. The remaining alternatives for controlling pollution; namely, subsidy, moral suasion, and taxation, have been overlooked because of the necessity for immediate action.

Economists such as Solow (1971) and Baumol (1972) have argued that standards are emergency measures and neglect the questions of benefits and costs on a regional scope. A much better solution is suggested in which effluent taxation would be imposed on polluters, who would then determine whether to clean their wastes or pay the taxes so such treatment could be provided.

The lower the marginal cost of pollution control from a source, the larger the reductions which can be achieved to avoid the corresponding tax payment.

Walker (1978) evaluated the taxation alternative for the Grand Valley. An updated summary of this work is included in the following discussion.

Grand Valley Economy

Sectors within the general economy are not isolated from each other, even though a considerable degree of specialization may be present. Thus, an analysis which focuses entirely upon a single sector, or even a limited number within the economy, can only effectively examine the behavior and problems internal to that specific sector. In the study by Walker (1975), the internal workings of the Grand Valley economy were not of primary concern, but rather, the linkage between the agricultural sectors and the rest of the local economy. This linkage describes the local impact either directly or indirectly that would result from taxing individual cropped acreages to effect a specified measure of salinity control. The basic analytical system used herein to achieve a description of the linkages is the "input-output" model described by Miernyk (1965).

The economic input-output model results in a business multiplier for each industry in the processing sector (which in this case is irrigated agriculture). The value represented by the business multiplier indicates the total economic production in the economy of the Grand Valley resulting from one dollar worth of output from an industry in the irrigated system (i.e., a crop). Thus, if the business multiplier for the alfalfa industry is 1.23, then the direct and indirect effects resulting from one dollar of production is an additional 23 cents. A summary of the crop industry business multipliers, along with those for the state as presented by Walters and Ramey (1973), is shown in Table 11.

TABLE 11. CROPLAND BUSINESS MULTIPLIERS PER DOLLAR OF PRODUCTION IN THE GRAND VALLEY (WALTERS AND RAMEY, 1973)

	Alfalfa	Corn	Orchards	Pastures	Grains	Sugar beets
Walker (1975)	1.23	2.20	2.24	1.31	1.51	2.53
Walters & Ramey (1973)	2.10	2.10	--	--	--	1.80

The use of the input-output model by economists is generally common practice because of its quantitative description of the economy of an area or a region. Data for these models usually are collected by field surveys and then reconciled with the secondary sources such as county agricultural statistics prepared by the Colorado Department of Agriculture. Thus, input data to the model are best developed by field experience and sampling data.

Alternative Taxing Schemes

The basis for deciding upon the structure of a taxing system may be selected from a number of alternatives which can be grouped into two classifications. The first is a taxing alternative in which assessments are made against selected salinity producing processes according to an objective of least-cost criteria. The second group of taxing alternatives are those restrained to applying some tax is to stimulate the structural and management improvements which would reduce salinity effects, all agricultural processes should be encouraged to alter existing practices. Three models must be developed before results can be generated relating to salinity control through taxation. The hydro-salinity model delineated the agriculture activities causing salinity and quantified their effects. An analysis of damages created through the use of saline water supplies in the Lower Basin identifies the damages originating in the Grand Valley by tracing the salinity concentrations back upstream. The linkage between these two models is the annual cost per metric ton of salt attributable to the Grand Valley. The interaction of the models and the input-output economy model for the Grand Valley establish a "pollution or salinity coefficient." The salinity coefficient is the linkage among the three models and is defined as the dollar cost of salinity related detriments per dollar of output from each economic sector in the local economy.

The salinity coefficients integrating the three modeling systems present some interesting alternatives for assessing taxes against the croplands in Grand Valley to affect salinity control. The formats of these alternatives are as follows: (a) directly related salinity damages; and (b) per acre equivalent salt loading; and (c) salinity coefficients; and (d) gross revenue.

The four taxing alternatives discussed above are by no means an exhaustive list of the possibilities, although they were selected to represent the set of taxing policies aimed at stimulating improvements in local irrigation systems. The purpose here is to illustrate how the linkage of economic and hydrologic models can be made to assess the concept of pollution taxation as a measure to effect solutions to water pollution problems.

A comparison of the taxing plans presented should center on two major questions: (a) how well will the measure induce local salinity control improvements; and (b) what would be the local economic impact of a taxing program.

More than one-half of the salt pickup in the Grand Valley comes from seepage losses in the water conveyance system. Existing plans indicate that the initial salinity control efforts will involve rehabilitation of canals, ditches, laterals, and their appurtenances. Such a program must be undertaken with the cooperation of local landowners because the system is privately owned and operated. However, the application of water on the croplands themselves also requires substantial improvement. Consequently, an important comparison of the taxation procedures would be how well they would encourage either self-improvement or offset the costs of having certain improvements made by others. Walker (1975) concluded that a system of taxation based on equivalent salt loading would be best suited for the local system because it exhibited the best balance between conveyance and on-farm improvements.

The equivalent salt loading concept is predicated on the basis that the primary unit in the salinity problems in the Colorado River Basin, at least so far as control is concerned, is mass or tonnage of salts being carried by the water flows. Under the equivalent salt loading approach, the respective allocation of taxes for any given level of desired salt loading reduction would be as follows:

Alfalfa	14.3%
Corn	17.8%
Orchards	12.1%
Pasture	15.2%
Grains	21.2%
Sugar Beets	19.4%

Application of Taxation

Taxation will not likely be employed to remedy the salinity problems in the Colorado River Basin. In the reports prepared during this study, the results of which are summarized herein, the costs of improving local agricultural practices to reduce salt loading are less than the currently reported damage figures until a program requiring a reduction of more than about two-thirds of the salt loading is reached. In other words, if the volume of salts to be eliminated from the Grand Valley return flows is less than about 350,000 to 400,000 metric tons, the taxes would always be higher than the actual costs. Consider the following example. Suppose the Grand Valley salt contribution was to be reduced by 200,000 metric tons annually. Further, assume that a metric ton per year contribution resulted in downstream damages of $150 (Valentine, 1974). The taxation approach would levy the following charges to the Grand Valley:

Alfalfa	$ 726/hectare
Corn	$ 922/hectare
Orchards	$1,293/hectare
Pasture	$1,092/hectare
Grains	$2,023/hectare
Sugar Beets	$2,734/hectare

As shown in the previous section, this amount of salinity can be reduced by an average expenditure of approximately $720 per hectare. Note that these are present value figures. If the desired salinity contribution was raised to 400,000 metric tons annually, the taxes would be less than the costs.

It is evident that taxation is a linear policy inasmuch as the tax is not related to the level of control. Consequently, taxation does not segregate the alternative measures for salinity control based on individual cost-effectiveness relations. On the other hand, the evaluation of salinity control alternatives using their associated cost-effectiveness functions automatically indicates the most cost-effective improvements as the salinity control programs are initiated. The taxation alternative has not been further considered.

Even though significant strides have been made towards pollution control, a critical problem remains for which neither the quality standard nor effluent tax can be properly applied. The problem is that a quantitative contribution to the diffuse pollution created by irrigation return flows is very difficult to ascribe to an individual water user.

LEGAL CONSIDERATIONS

Beneficial Use

A major legal problem that is universal throughout the 17 western states is the failure to enforce the concept of beneficial use provisions of the law. The reason is twofold. One has to do with the fact that the definition of beneficial use is nebulous and, thus, lacks appropriate direction for administrators to follow or courts to interpret. The second derives from a lack of social consciousness on the part of water users so that the burden of proving nonbeneficial use is upon the state, which is really an administrative impossibility. Generally, our system of water law places emphasis upon the *right* to use water, not the *duty* to use it appropriately.

Cases in Colorado and other western states reflect the difficulty of enforcing the general concept of beneficial use under which water is allocated and the exercise of the right to use follows. It is suggested, therefore, that the State Engineer's Office develop and adopt criteria for beneficial use as an agency rule or regulation. These criteria for use will in effect define the standards of water use efficiency in the conveyance and application of water under the exercise of a water right relative to quantity diversions, water use, and quality discharge. They will also provide the basis for shifting the burden of proper use of the public resource upon the benefactor (both purveyor and user) and in essence identify the duty for delivery, use and removal of water.

Influent Standards

As stated earlier in this report, the demonstration project used each lateral as a subsystem because this provided control at the lateral turnout gate. This turnout gate is a critical control point in the irrigation system because it represents the terminal point of responsibility for most of the irrigation companies in Grand Valley (in some cases, under the Grand Valley Water Users Association, there is responsibility along the upper portions of the lateral). In turn, the control point for each irrigation company is the point of diversion from either the Colorado River or Gunnison River. The responsibility for these river diversions belongs to a water commissioner who is a state employee, while the amount of water discharged at each turnout gate along a canal is the responsibility of water masters or ditch riders, who are employees of the particular irrigation company.

Proper operation of an improved lateral subsystem will result in a significant reduction in the discharge requirement at the turnout gate, as compared with lateral diversions prior to an improvement program. Since the lateral turnout gate is an important control point, standards for water use could be applied at each turnout gate, which could be classified as an influent pollution control standard. An initial influent standard goal should be the intended water duty for the irrigation lands. This should be measured at each farm inlet, which can then be translated back to the lateral turnout gate taking into consideration lateral seepage losses (which could be essentially ignored if the laterals were lined or converted to pipelines). An important consideration should be to use either a volumetric water duty as a standard, or a variable flow rate which is dependent upon the changing water requirements of the crops during an irrigation season.

The approach of using influent standards has the advantage of alleviating the salinity problem by improved water management practices, rather than end-of-pipe treatment, or partially reducing the salt load by using effluent standards under a permit program. The success of an influent approach is dependent upon: (a) use of numerous flow measuring devices; (b) adequate technical assistance for working with and advising farmers on improved irrigation practices and methods; and (c) availability of funds for making the necessary structural improvements.

Development of a Water Market

The establishment of a water market would alter the present institutional arrangement, so it would seem desirable from a practical standpoint to alter that arrangement as little as possible in order to assure its acceptance. In order to minimize the disruption to the present institutional arrangements for allocating irrigation water, a water rental market could be established. Under such an arrangement, a water rental market would utilize the present structure of water rights and allotments and would permit the rental of surplus water to upstream water users (with the "rental" waters retaining their original appropriation dates) without jeopardizing these rights and allotments.

There is a legal requirement that water transfers not injure other water rights. In most cases, transfers must be restricted to the amount previously used consumptively; however, since the return flows from the Grand Valley are not reused in the State of Colorado, there would be no downstream damages to water rights holders by transferring water upstream of Grand Valley. Such transfers will not be detrimental to downstream users so long as the State of Colorado does not exceed its entitlement to the Colorado River, which presently is not the case. In addition, the Grand Valley Irrigation Company holds the first priority water right on the Colorado River within the boundaries of the State of Colorado. There are many other early priority rights held by the various irrigation companies in Grand Valley. The "Cameo Demand," which is the required water deliveries as measured at a USGS stream gaging station located on the Colorado River upstream from Grand Valley, is for 1,850 cfs during the irrigation season. These rights are for irrigation and hydropower. This "Cameo Demand" has a definite impact upon the value of upstream junior water rights, as well as future upstream water resources development.

The Upper Colorado River Basin, because of its vast reserves of oil shale and near-surface coal, is becoming one of the most important areas in the Nation for energy development. However, energy development will also result in increased salinity levels in the Colorado River unless mitigating alternatives are employed. There may be some advantages in allowing the water quality degradation resulting from an energy complex to be offset by improvements at another location in the river system, usually within the same state boundaries. One of the most viable off-site alternatives is irrigation improvements in agricultural areas. In particular, the Grand Valley offers a unique opportunity for coordinating energy development with improved irrigation water management. An energy complex could make sufficient investments in irrigation improvements to almost exactly offset the salinity detriments resulting from the energy complex operation, thereby satisfying the nondegradation policy for the basin. Such investments have the added advantage of increasing agricultural productivity. Also, irrigation improvements in such areas would decrease the diversion requirements, which could in turn be transferred upstream. This decreased diversion requirement provides additional opportunities for improved basinwide water management provided changes in Colorado water laws can be achieved (Skogerboe et al., 1975).

An impediment in the exercise of water rights is the transfer restriction of rights within an irrigation system to other uses, or outside of the basin. This constraint may exist in the substantive water law or as a result of the organizational and administrative system of the state. There are few states that prevent the sale and transfer of water rights to other present uses. States restricting transfers rely upon the appurtenancy concept to prevent such shifts. However, the law should be modified or changed to reflect state encouragement in the renting, leasing, transferring or selling of water rights to other uses and places so long as the vested rights of others are protected. Although there are no restrictions on the transfer of water rights in Colorado, the organizational red tape--delay and expense--acts as an impediment. Changes in the administrative and judicial system should be made to facilitate exchanges of water rights. Recognition of such a right and a change in the concept of beneficial use to include recreation, aesthetics, fish and wildlife and other beneficial uses would serve to nullify the fear of losing that portion of the water right not exercised by permitting the transfer of the unneeded portions to other uses within the system.

Removing these rigidities in the law to give the water right holder greater freedom and flexibility will eliminate many of the irrigation problems perpetuated by the appropriation doctrine. A legal solution would be to merge the economic benefits from a more liberal transfer policy into legal guidelines that still provide protection to existing water right holders. This would require the adoption of an incentive mechanism to encourage water users to "market transfer" some of their water through the irrigation companies (i.e., Grand Valley Irrigation Company or Grand Valley Water Users Association), or possibly through the Grand Valley Canal Systems, Inc. Water could be rented or leased to upstream water users (i.e., other irrigators or new energy complexes) with the revenues being used to further improve the irrigation system in Grand Valley.

A substantive change in the water laws affecting the administrative organization of the state which should be enacted to enable a greater degree of cooperation between the state agency and water users, and at the same time permit the state to concentrate on the development of a desirable state water plan, is to enact legislation permitting the state water resources agency or other public organizations the right to acquire water through appropriation, purchase, abandonment or condemnation. The significance can be seen at the state and interstate level by granting the state greater freedom in carrying out its responsibilities and negotiating agreements with its water users and other states.

What is needed is a means of allocating and reallocating water within the irrigation system by an organization cognizant of the needs of water users within the system, the state water development plan, and the basin and international impacts. The development of a centralized state brokerage system is suggested which would be operated as a market center for the exchange and sale of water rights, or renting of water available under the rights held (Radosevich, 1972).

This brokerage system could be organized as a public or private institution. Water users would be permitted to divert only that amount of water necessary for their operation, without fear of losing the unused decreed quantity, and lease or rent the difference to other users. Hence, there would be an economic incentive to implement more efficient irrigation water management in an attempt to reduce the quantity of water applied.

A brokerage system created as a public entity could be established in the Office of the State Engineer or water planning and resource department (i.e., Colorado Water Conservation Board). These offices or their respective divisional offices in the various basins within the state would list all available water for rent, lease, exchange or sale. The location of available waters will determine the impact upon other vested rights, but the responsibility for delivery and protection of such other rights would rest upon either the water right holder or water acquirer. Uniform prices for units of water could be established, or the available water could be transacted to the highest bidder. The adoption of such a system in state organization would require changes in agency laws to permit this type of activity. Likewise, it would be imperative that the state should have the power to purchase, condemn or receive water rights in the name of the state. This would allow the state to take action against appropriators who refuse to implement efficient practices, acquire their unused rights, and retain them for future use while renting or leasing the water during the interim. A percent of the transacted price would be retained for the operation and maintenance expense of the brokerage system (Radosevich, 1972).

SECTION 8

IMPLEMENTATION

BASIC PROGRAM

The optimizational analysis of the cost-effectiveness functions for the various salinity control alternatives clearly shows that the basic program which should be implemented consists of lateral lining and on-farm improvements. Depending upon the level of salt load reduction being sought, after implementing lateral lining and on-farm improvements, the next priority would be concrete lining of the Government Highline Canal. At this point, the implementation of these technologies at the investment levels indicated in Figure 18 would be economically feasible based on downstream damages alone, without taking into consideration the local benefits to the farmers and people living in the Grand Valley. However, it may be possible, if similar analyses were done for each of the irrigated areas in the Upper Colorado River Basin, that concrete lining of the Government Highline Canal would not be as cost-effective as lateral lining and on-farm improvements in other areas (i.e., lateral lining and on-farm improvements in the Gunnison Valley may be more cost-effective than concrete lining the Government Highline Canal).

Lining the Government Highline Canal is the easiest technology to implement because this canal was originally constructed as part of the USBR Grand Valley Project, and the USBR would be technically responsible for the construction of the concrete lining. The implementation of lateral lining and on-farm improvements is not so easy. First of all, lateral lining should not be implemented by itself, followed by on-farm improvements. Instead, lateral lining and on-farm improvements must be planned simultaneously with the participation of the water users under each lateral. Otherwise, the full potential benefits of the lateral lining will not be realized. A significant point to bear in mind is that the construction of physical improvements only increases the *potential* for improved water management (and consequent salt load reduction), while the operation and management of these new physical facilities dictates the degree to which this potential is realized. As stated earlier in this report, irrigation scheduling would be a necessary requirement in achieving the potential of the on-farm improvements.

In fact, each lateral must be managed as a subsystem in order to effectively improve the water management on the croplands. The discussion which follows is pertinent to the implementation of a combination of lateral lining and on-farm improvements on a lateral-by-lateral basis.

IMPLEMENTATION ACTIVITIES

Considerable experience has been gained in working directly with farmers during the life of the Grand Valley Salinity Control Demonstration Project. These experiences and farmer feedback in recent years and during the Irrigation Field Days, plus research findings, provide a basis for the development of some broad guidelines for a program to implement a combination of lateral lining and on-farm improvements. The specific objectives of such an implementation program are as follows: (a) encourage farmer participation; (b) train field personnel; (c) organize water users; (d) develop basic farmer training materials; (e) recognize the efforts of farmers; and (f) evaluate implementation activities.

This section of the report provides a brief discussion of suggested means to attain these objectives. This includes methods to obtain farmer participation, the training of field-level personnel, the development of basic training materials, and methods for encouraging farmer organizations. The underlying philosophy and assumptions of the discussion are: (a) that the findings of the present research and improvement activities at Grand Junction are applicable for other irrigated regions; and (b) that a successful comprehensive salinity control program requires active farmer participation.

Farmer Participation

One of the unique characteristics of improving on-farm water management is that the degree of success is highly dependent upon the degree of participation of each individual farmer, as well as their ability to cooperate collectively for the common good of all water users. The construction of on-farm physical improvements only provides an increased potential for water use efficiency, whereas the degree of potential which will be achieved is dependent upon the operation, management, and maintenance of the physical improvements. This, in turn, is dependent upon the level and ability of technical assistance provided, farmer attitudes, and the degree of credibility between those individuals providing the technical assistance and the farmers involved.

Credibility and acceptance by the farmers begins when the basic training and motivational materials are initially used to describe the problem. Efforts to organize the water users under each lateral provide an opportune time to develop early rapport with the farmers. Credibility and acceptance of the technical personnel by farmers during the planning and implementation of individual farm plans for improved water management is essential to the long-range goals of a control program. Credibility and good communication must exist during the collective negotiations in determining the physical improvements to be made on a lateral. Farmer participation is crucial during these stages in order to evolve a plan of development which is acceptable to the water users and also satisfies the goals of the salinity control program.

The final step in this process dictates the real success of the entire program. After spending vast sums of money to construct physical improvements, the test of effectiveness centers largely around the operation, management, and maintenance of these improvements. This is the phase of the work where the rapport developed with the farmers pays huge dividends. Unfortunately, this step is very time-consuming and most frequently neglected. Considerable evaluation is required to "tune-up" these new improvements so that they are operating at their potential, and the key variable in this operation is the farmer decision maker.

Training Field Personnel

The primary agency providing technical assistance to farmers for a salinity control program will likely be the SCS. The SCS will likely cooperate with the USBR in the provision of required technical assistance. Given the levels of manpower needed to work with farmers, and the current shortage of trained manpower with on-farm water management experience, special short courses for training personnel will likely be required. As a complement to technical competence, personnel working directly with farmers should know how to develop good working relationships with farmer clients and have definite skills and knowledge related to organizing farmers into water user associations for action programs. Personnel also must have the capabilities required for assisting farmers in "tuning-up" furrow irrigation practices and the maintenance of improved conveyance systems.

Technical assistance to farmers will include convincing them to use "scientific" irrigation scheduling procedures and other improved irrigation practices. The focus on improved irrigation scheduling is essential because the existing piecemeal methods of scheduling in Grand Valley have been found to be inadequate as an individual salinity control measure.

Water User Organizations

A crucial element in implementation of an effective salinity control program is gaining the participation of the users. The unit of organization should be the lateral subsystem because it is a natural hydrologic unit where farmers know each other and interact on a day-to-day basis. In Grand Valley, the jurisdiction of the irrigation companies does not include the laterals in most cases; so, there is an organizational vacuum for most laterals. The goal should be to gain participation by all water users on each lateral. This may not always be possible due to human problems. While the organization could be on an *ad hoc* or informal basis, experience indicates that it is probably best to aim for a formal organization with rules developed by the members themselves. A formal organization with its own rules and regulations also makes it easier for the implementing agency because all parties have a knowledge of the structure and mechanisms involved. When the leadership is defined, this facilitates the work of the implementing agencies.

For example, the water users on several laterals in the Grand Valley have organized formally as nonprofit mutual irrigation companies under the state laws of Colorado. One problem the members of these associations have encountered has been lawyer fees for incorporation. This can be partially overcome by providing model sets of bylaws and other provisions to farmers considering such organization. In fact, alternative models can be provided farmers, and they should decide the set of rules and regulations which meet their special needs for the most effective means of operation and maintenance of the lateral subsystem. These models could be provided in a well-prepared manual or booklet and made available to interested farmers. The booklet should explain the benefits of formal organization, how to organize legally, and the types of bylaws and provisions required. It is important that such a booklet be well illustrated and in easily understood language. Often such booklets are not well prepared and contain too much legal jargon which farmers cannot fully understand. The goal is to design usable materials on how-to-do-it for the farmer audience.

Basic Farmer Training Materials

Materials are needed to motivate farmers and help them understand the importance to themselves and their communities of improving present water management practices for increased crop production and the control of salinity. Data obtained in problem identification and alternative solutions to the problem should be utilized in preparing well-illustrated materials for farmers. These materials should graphically and clearly define the problem, explain its consequences, document the contributing factors, and explain the costs and benefits. Alternative solutions should be carefully delineated and estimated costs presented.

Techniques for such communications could include slide shows, an easy-to-read booklet, and selective use of local mass media channels. The slide show developed for the Grand Valley

Salinity Control Demonstration Project has been well received and has been presented many times in the community at special public meetings and for civic groups (Bargsten et al., 1974). Since a comprehensive salinity control program requires changes in attitudes and behavior wherever such programs are proposed, the first major consideration should be the design of definite communication strategies. To make the program successful in reaching all water users and the community, several complementary communication methods should be used over time to reinforce the central messages. Local conditions and communication sources and channels need to be identified and used with imagination. Essentially, salinity control is a problem of water conservation which requires much education on the part of farmers and communities.

Farmer Client Recognition

The Irrigation Field Days held at Grand Valley, and other experiences, have demonstrated the importance of farmer recognition. Farmers usually can sell a program to other farmers more successfully than public officials. Where possible, farmers should be given special recognition, because the success of any salinity control program rests finally with the degree of participation by the farmers themselves. There are a number of methods which can be effectively utilized for using farmer recognition to motivate other farmers.

The proper use of radio and television announcements and newspaper articles can be of considerable help in fostering enthusiasm for the program. The local newspaper provides excellent coverage on news related to natural resouces and agriculture. The local newspaper in Grand Junction has been very helpful and always willing to include news articles pertaining to the Grand Valley Salinity Control Demonstration Project. The television station and some radio stations in Grand Junction have cooperated with the project in disseminating news related to the salinity control research activities.

The news media, in addition to news reports about current activities of the salinity program, are also very interested in covering human interest stories. If these human interest reports and farmers' testimonials are well prepared, they can create much interest in other farmers for the programs. Such publicity is free and probably can generate better image-building for the state and federal agencies than they can do for themselves.

Awards should be given to those farmers who have made exceptional progress in improving their on-farm water management practices. Awards for providing leadership in the water user association under each lateral should be considered. Awards presented to each water user served by the lateral demonstrating the most efficient use of water would be highly effective in promoting the goals of an improvement program. News media coverage of such awards also provides additional incentives for improved water management on the part of other farmers. Framed photographs of farmers engaged in improvement activities with an inscription could be considered for presentation. Plaques could be presented to cooperators to show appreciation for their contributions.

An excellent method of employing farmers for promoting wide interest in a project once substantial progress has been made in an improvement program is the use of field days. In the Grand Valley, a Field Day could be held annually which would involve strong participation by local farmers. Water users and irrigation company leadership from other valleys in the Upper Basin could be given special invitations to attend the Field Day in order to observe firsthand the implementation of a salinity control program. In addition, special tours could be arranged during other times of the year for a group of irrigators from any particular area to visit the Grand Valley and meet with farmers who have participated in the program. The emphasis should be farmer-to-farmer interaction, with the Grand Valley farmers being highlighted, rather than technical assistance personnel. These personnel, however, should play a strong backstage role in facilitating this interaction.

Evaluation and Refinement of Implementation Activities

Evaluation research techniques are available which, if properly utilized, can be used to determine the strengths and weaknesses of project implementation. Information from such evaluative studies is needed by sponsoring agencies and by project implementors to discover the most effective and efficient methods of working cooperatively with farmers. Continual and periodic evaluation mechanisms are needed in order to continually refine the implementation program. Feedback is needed both from farmers and technical assistance personnel for improving: (a) the delivery of the salinity control technological package; (b) the operation and management of the physical improvements; and (c) the cost-effectiveness of the entire program. Credibility with the farmers will be strengthened by continually refining and improving the implementation program.

Extension communication strategies should be designed into the project work plans in order that various techniques can be effectively evaluated. While technical expertise for such programs is usually adequate, there is a general weakness in designing and evaluating extension communication strategies. Technical assistants should be given short courses in skills needed for working effectively with farmers. As stated often in this report, the key variable in achieving successful program implementation and long-term effective management of improved systems is the farmer client himself. Consequently, communication techniques used for working with farmers as individuals and groups should be designed into the implementation program and evaluated to the same degree as the technical components and activities.

INSTITUTIONAL ARRANGEMENTS

Lateral and On-Farm Improvements

As stated earlier, lateral lining and on-farm improvements should not be separate programs, but rather a single program which is planned and developed with participation by the affected water users on a lateral-by-lateral basis. Presently, the responsibilities are being divided between the USBR for lateral lining and the SCS for on-farm improvements. There is a serious question as to whether or not these components, which are the "heart" of an action salinity control program for Grand Valley, should be divided between two federal agencies. Besides the problems of coordination between federal agencies and having two separate agencies interacting with the farmers, this report has shown that the difference in costs for lateral lining will vary significantly depending on which agency is responsible. Using 1976 costs, the writers have estimated that the SCS can accomplish the lateral lining program at a cost of $10 million, while the USBR estimates the cost of $30 million. In addition, the SCS program would have the advantage of allowing participation by farmers when pipelines are installed, which is of considerable help to farmers in: (a) meeting their cost sharing requirements; (b) developing a better understanding of how the newly improved lateral subsystem will operate; (c) developing a pride in the improvements; and (d) having a commitment to effectively manage and maintain the new improvements.

This particular program of lateral lining (or pipelines) and on-farm improvements could be initiated immediately. In implementing such a program, there is a question as to whether or not the construction activities should be scattered throughout the Grand Valley to serve as demonstrations to nearby farmers, or whether these improvements should be concentrated at the lower end of the Valley and then moved upstream with time. The advantage in beginning at the lower end of the Valley is that after completion of construction, and then operation for a few years, the required diversion at each lateral turnout gate would be more accurately known, which would allow a more proper sizing of the canal section for purposes of concrete lining. The canal lining program should begin at the lower end of Grand Valley, with the lining program moving up the Valley with time.

Lining Government Highline Canal

The decision of whether or not to concrete line the Government Highline Canal is dependent upon the desired level of salt load reduction from Grand Valley, which in turn is dependent upon the cost-effectiveness of alternatives in other irrigated areas of the Upper Colorado River Basin. At this time, studies have not been completed which would allow a comparison of lining the Government Highline Canal with salinity control alternatives in the Gunnison Valley, Uinta Basin, etc. Besides waiting on the completion of basinwide studies before making a decision whether or not to proceed with a lining program, there are some other advantages in postponing a decision:

1) The program of lateral lining and on-farm improvements needs to be underway, and a number of improved lateral subsystems operated for a few years, in order to accurately determine how much present lateral diversions can be reduced, so that the canal will be properly sized, rather than constructing a canal which would have a larger capacity than necessary.

2) The opportunities for lining the Grand Valley Canal, discussed below, which involves the institutionalization of a water market, would also prove advantageous in facilitating the lining of the Government Highline Canal.

The primary disadvantages in postponing a decision to line the Government Highline Canal are: (a) rising construction costs; and (b) allowing higher salt loads to continue entering the Colorado River during the interim.

Lining Grand Valley Canal

In Section 7, the development of a water market for Grand Valley was discussed. The lateral lining and on-farm improvement program will result in a decreased discharge requirement at the lateral turnout gate. State legislation would be required to allow this water savings (only a part of this savings is a reduction in consumptive use by phreatophytes) to be transferred for use upstream through a rental or lease agreement. The revenues from these transfers can be used for irrigation scheduling (as discussed below) and canal lining.

Since the Grand Valley Irrigation Company (Grand Valley Canal) has the first priority water right on the Colorado River (in the State of Colorado), any water savings under this system would be extremely valuable to upstream water users. The results of the cost-effectiveness and optimization analysis described in Section 6 shows that lining the Grand Valley Canal has an average cost of about $500 per metric ton of salt reduction. In comparison, the average reduction cost per metric ton of salt load reaching the Colorado River is $300 for lining the Government Highline Canal and $50 to $100 for lateral lining and on-farm improvements. Consequently, for every $0.60 of water rental revenue applied to lining the Grand Valley Canal, the Federal Government could consider a cost sharing of $0.40 in order to make the salinity control cost-effectiveness of the Grand Valley Canal System in line with that of the Government Highline Canal.

Allowing new industries, such as energy complexes, and new interbasin water transfers to offset their salinity detriments (which are primarily salt concentrating effects) by lining a sufficient length of canal in Grand Valley would be highly advantageous because of the additional benefits resulting from increased agricultural productivity, as well as water savings from reduced seepage losses. Rather than allowing these new water users to offset their salinity detriments by lining the Government Highline Canal, which would cost less, there are a number of advantages in requiring that the Grand Valley Canal be lined: (a) there is a lack of options for lining the Grand Valley Canal; (b) having the first priority water right on the river means that any water savings (i.e., reduced seepage losses resulting from canal lining) has a higher revenue value than any other water right, which will provide funds for additional canal lining; and (c) the cost to new water users (energy complexes, other industries and cities) is still relatively insignificant.

Irrigation Scheduling

In implementing the program for lateral and on-farm improvements, irrigation scheduling will have to be a strong component. For a number of years, the technical assistance personnel will have to take responsibility. The USBR presently has an irrigation scheduling program in the Valley and would appear to be the logical agency to continue this activity. However, if the SCS is going to have the responsibility for the lateral and on-farm improvements, then there is some advantage, because of their continual interaction with farmers, for the SCS in collaboration with the Agricultural Research Service (ARS) to handle the responsibility for implementing irrigation scheduling on improved lateral subsystems.

After a number of years, the irrigation scheduling program should be turned over to private commercial organizations, the irrigation companies, or the Grand Valley Canal Systems, Inc. There are two options in obtaining revenues to provide this service, either charge the farmer through his annual water assessment fees or utilize water rental revenues. The advantages in having the Grand Valley Canal Systems, Inc. take responsibility in later years for an irrigation scheduling program are: (a) all of the canals in the Valley could be operated as a system; (b) the management capability of the local irrigation interests would be strengthened; and (c) there would be more involvement by irrigation company leadership in the equitable distribution of water to irrigators.

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